Instrumentation Requirements for Marine Fuel Gas Supply Systems

Jimmy Remsu

Degree Thesis for Bachelor of Engineering

Degree Programme in Electrical Engineering and Automation

Vasa 2020

BACHELOR'S THESIS

Author: Jimmy Remsu
Degree Programme: Electrical Engineering and Automation
Specialization: Automation
Supervisor(s): Matts Nickull, Björn Nygård

Title: Instrumentation Requirements for Marine Fuel Gas Supply Systems

---

Date: April 9, 2020 Number of pages: 53

Abstract

This thesis was commissioned by Wärtsilä Marine Business. The increasing demand of environmentally sustainable fuels has resulted in rapid growth of the LNG market. The Fuel Gas Supply Systems business line works with the design of a marine fuel gas supply system called the LNGPac^{TM}. The aim of this thesis was to establish an easily updated document containing the latest instrumentation requirements set by IMO for the safety and reliability of a marine fuel gas supply system, along with four classification societies' interpretation of IMO's rules and regulations.

A research was carried out, providing information about the organizations followed by a more technical background. An extensive study of five set of rules was conducted for gathering of the instrumentation requirements demanded by the International Maritime Organization, Bureau Veritas, Lloyd's Register, American Bureau of Shipping and Det Norske Veritas Germanischer Lloyd.

The result are documents containing four classification societies' and IMO's requirements on instrumentation for marine fuel gas supply systems. The result include where and why process variables are needed to be measured, together with safety actions required to be taken. As there are numerous other classification societies, along with new versions of these four set of rules being periodically released, the documents can be further developed. The wiki containing the documents is classified.

Language: English Key words: Fuel gas supply system, classification society, instrumentation, LNG

EXAMENSARBETE

Författare: Jimmy Remsu
Utbildning och ort: El- och automationsteknik, Vasa
Inriktningsalternativ: Automationsteknik
Handledare: Matts Nickull, Björn Nygård

Titel: Instrumenteringskrav på marina gasbränslesystem

Datum: 9.4.2020 Sidantal: 53

Abstrakt

Detta examensarbete är gjort på uppdrag av Wärtsilä Marine Business. Den ökade efterfrågan på miljömässigt hållbara bränslen har resulterat i snabb tillväxt på LNG-marknaden. Affärsområdet Fuel Gas Supply Systems arbetar med designen av ett marint gasbränslesystem som kallas LNGPac^{TM}. Målet med detta examensarbete var att upprätta ett dokument som innehåller de senaste kraven på instrumentering, bestämda av IMO för säkerhet och pålitlighet för ett marint gasbränslesystem, tillsammans med fyra klassningssällskaps tolkningar av IMO:s regler och bestämmelser.

En undersökning genomfördes för att få information om organisationerna, följt av en mera teknisk bakgrund. En omfattande studie av fem regelverk utfördes för att samla kraven på instrument ställda av International Maritime Organization, Bureau Veritas, Lloyd’s Register, American Bureau of Shipping och Det Norske Veritas Germanischer Lloyd.

Resultatet blev dokument som innehåller fyra klassningssällskaps och IMO:s krav på instrumentering för marina gasbränslesystem. Resultatet inkluderar var och varför processvariabler måste mätas, tillsammans med säkerhetsåtgärder som måste tas. Eftersom det finns åtskilliga andra klassningssällskap, jämte nya versioner av dessa fyra regelverk, publicerade med jämna mellanrum, kan dokumenten utvecklas ytterligare. Wikin som innehåller dokumenten är hemligstämplad.

Språk: engelska Nyckelord: gasbränslesystem, klassificeringssällskap, instrumentering, LNG

Table of Contents

Table of Figures

Abbreviations

ABS	American Bureau of Shipping
BOG	Boil-Off Gas
BV	Bureau Veritas
DNV GL	Det Norske Veritas Germanischer Lloyd
ECR	Engine Control Room
ESD	Emergency Shutdown
HMI	Human Machine Interface
IGF Code	International Code of Safety for Ships using Gases or other Low-flashpoint Fuels
IMO	International Maritime Organization
LEL	Lower Explosion Limit
LNG	Liquefied Natural Gas
LR	Lloyd’s Register
NG	Natural Gas
PLC	Programmable Logic Controller
VFD	Variable Frequency Drive

1 Introduction

This thesis was commissioned by Wärtsilä. The thesis is a study of classification societies' interpretation of the IGF Code. Both IMO's and classification societies' requirements on instrumentation for marine fuel gas supply systems will be studied. Fuel Gas Supply Systems is the business line I have been working at since the summer of 2019. After working as an E&A design engineer for less than a year, a repetitive problem has been noticed. This problem is that the requirements demanded by classification societies is not clear, which at the end will result in a massive number of extra hours of design work, as drawings need to be updated whenever a forgotten, misunderstood or new class requirement occurs.

A topic that has been hot for the last 20 years is the environmental sustainability. This has resulted in new technologies and development of alternative fuels to fossil fuels. One of the alternative fuels is LNG, Liquefied Natural Gas. The Fuel Gas Supply Systems organization was shaped as an outcome of the environmental way of thinking.

The nature of gas as fuel in ships is hazardous. If the fuel is not handled correctly severe accidents can easily be caused. In order to get a safe and sustainable design and operation of gas-fueled ships, the IGF Code was created to ensure that minimum requirements are complied with for a safe and reliable operation of the fuel handling system. In addition to the IGF Code, classification societies have released their own interpretations of the IGF Code.

The IGF Code's and four different classification societies requirements regarding the monitoring and control of equipment, as well as safety systems on ships that uses gas as fuel will be covered in this thesis. The areas of the IGF Code and classification societies' rules that will be covered in this thesis is process instrumentation, leakage detection, gas detection, ventilation, double walled pipes and fire detection.

1.1 Background

Wärtsilä, celebrating its 186th anniversary in 2020, is one of the world leaders in smart technologies and lifecycle solutions for both energy and marine markets. With its roughly 19,000 employees, Wärtsilä strives to meet the world's demand for sustainable energy and to enable sustainable societies with smart technology. Wärtsilä operates in more than 80 countries and in over 200 locations. About 20% of Wärtsilä's employees are located in Finland. Wärtsilä is divided into two businesses. Those two are Marine Business and Energy

Business. The Marine Business tries to create a Smart Marine Ecosystem and sustainable shipping where only the cleanest fuels are used. The Energy Business strives to lead the evolution of a 100% renewable energy future. Wärtsilä power is found in 180 countries around the world.

1.2 Fuel Gas Supply Systems

The business line this thesis work is commissioned by is called Fuel Gas Supply Systems. This organization was setup in 2013, with about 35 employees in the end of 2018 and has grown into nearly 80 employees at the time of writing. The increasing demand of environmentally sustainable, efficient and flexible products has resulted in the establishing of this business line. Fuel Gas Supply Systems is a profitable and fast-growing organization within Marine Gas Solutions developing environmentally sustainable shipping solutions. This organization not only offers complete systems for liquefied natural gas. The fuel gas supply system is developed, marketed, sold, designed and delivered by this organization. This requires a team of electrical & automation engineers and mechanical engineers, as well as process engineers. The two products this organization has to offer are the LNGPac^{TM} and the GVU. This thesis will only cover one of the products, the LNGPac^{TM}.

1.3 Purpose

Every project has a different design of the LNGPac^{TM}. The different designs are results of customer's different requirements on the system, but the design is also dependent on what classification society a project is assigned. There are several different classification societies requiring different kinds of design of a fuel gas supply system. The dissimilar requirements demanded by different classification societies have caused a very time-consuming design of the LNGPac^{TM}.

The purpose of this thesis is to allow for a less time-consuming design the LNGPac^{TM}. When designing a gas fuel handling system, there are many requirements that needs to be fulfilled. The IGF Code needs to be followed, but also the assigned classification societies' rules. To clarify, each project only needs to meet the requirements of one of the classification societies.

The goal of this thesis is to create a document that is easy to search in and easy to read. This document shall contain the IGF Code's latest requirements for the fuel gas supply systems, as well as four different classification societies' requirements. The classification societies included in this thesis are Det Norske Veritas Germanischer Lloyd (DNV GL), Bureau

Veritas (BV), Lloyd’s Register (LR) and American Bureau of Shipping (ABS). These four classification societies’ rules differ a lot from each other. Therefore, an easy read document containing the latest requirements would be needed. The document is also intended to be easy to update, as the classification societies update their rules, with additional or changed regulations on a regular basis.

The result of having a document like this would be that all minimum required process instruments, gas detectors, ventilation monitoring and double walled pipe monitoring would be included in the very first revision of the P&ID for a project, allowing for fewer changes to be made along the progression of a project.

1.4 Methods

Material for the theoretical background will mainly be gathered from different websites. Information about the International Maritime Organization and classification societies can be found on the organizations’ web pages. The approach that will be taken for gathering information for the technical aspect of the theory will be to study the instrumentation and components that are commonly used in industrial applications to get as relevant information as possible. To accomplish this, visiting manufacturers’ webpages will be the best way for gathering of information about instrumentation used in the industry. From this, a good understanding of how different types of sensors work will be acquired. To get a more detailed understanding of working principles of different types of sensors, a few books will be studied as well.

As the purpose of this thesis work is to make a document that contains the IGF Code’s and classification societies’ requirements for instrumentation, the rules and standards are needed to be studied. The methodological approach to take will naturally be to study the IGF Code first, as the classification societies’ rules are based on the IGF Code. While studying the IGF Code, the needed requirements must be highlighted and shortly described in a document.

After having the IGF Code studied, the classification societies’ rules need to be investigated. In the same way as for the IGF Code, the requirements related to this thesis has to be summarized in a document to keep track of what requirements that has been covered. Having all classification societies’ requirements gathered in different documents with a similar layout will ease the process of establishing the final document in a perspicuous way.

2 Theoretical background

The International Maritime Organization is the organization that sets the rules and standards for the maritime business. Classification societies make their own set of rules, based on the rules published by IMO. Natural gas, with its hazardous characteristics, will be described, accompanied by a second type of gas used for safe operation of marine fuel gas supply systems.

A technical background will be presented, describing different parts of the marine fuel gas supply system referred to in the rules and regulations. The different parts of a marine fuel gas supply system will be explained on a general level. Furthermore, the technical part will include descriptions of how a marine fuel gas supply system works. The second part of the technical theory is explanations of different types of industrial sensors that are used in processes and systems operating with the hazardous natural gas. A couple of essential parts of an automation system, or control system, such as PLCs and HMIs are also described in the technical theoretical background.

2.1 International Maritime Organization

The International Maritime Organization, IMO, is a 72 years old specialized agency appointed by the United Nations. IMO is responsible for the environmental performance, i.e. prevention of marine and atmospheric pollution caused by ships. The safety and security of international shipping are also IMO’s responsibilities. IMO is the authority that sets global standards for these areas. (International Maritime Organization)

Shipping is an industry that the world relies on, as shipping transports more than 80 percent of global trade to societies all over the world. (International Maritime Organization) International shipping is required to be a safe and efficient industry, which is why IMO’s standards and regulations are so crucial. One of the major priorities of IMO is to promote sustainability within shipping and maritime development. This organization has developed and released numerous rules and standards for shipping, and one of them is the IGF Code.

2.1.1 IMO 2020

Regarding the environmental part of IMO’s responsibilities, IMO has issued a restriction about sulphur oxide emission that becomes effective as of 1 January 2020. This sulphur 2020 limit is called IMO 2020. Sulphur oxides, SO_X, is not only a harmful emission to human health, but to the atmosphere as well. SO_X in the atmosphere can cause acid rain which will damage forests and harvests. Additionally, it will play a role in acidification of the oceans and injure animals and plants living in the oceans. The outcome of limiting SO_X emissions would be better air quality and protection of the environment.

The intention of IMO 2020 is to reduce the permitted amount of sulphur in ships' fuel oil from 3.50% to 0.50%. This practically means a 77% drop in SO_X emissions from ships around the world. Most ships will meet this limit by switching to higher quality fuel oil, but if there is a will to avoid being restricted to fuel oil with 0.50% sulphur content, LNG is an excellent alternative fuel. (International Maritime Organization, 2020)

2.1.2 IGF Code

The IGF Code is the abbreviation of "*International Code of Safety for Ships using Gases or other Low-flashpoint Fuels*". This Code was developed for a variety of ships that uses gas or other low-flashpoint fuels. The purpose of this Code is to provide an international standard for ships using the mentioned fuels. Using gas as fuel involves risks and may cause severe damage to the ship, the crew of the ship and the environment if it is not handled correctly. An attempt to minimize these risks resulted in the IGF Code, where required standards for arrangement and installation of equipment, machinery and fuel handling systems are specified. Safe and reliable operation of fuel handling, fuel supply and bunkering will be achieved when this Code is followed.

The part of the IGF Code that will be covered by this thesis is part A-1. In part A-1, requirements for natural gas fuel and fuel gas handling systems are found. Functional requirements regarding monitoring, control of equipment and safety systems are the important parts that will be studied for this thesis. Since new fuels technology is evolving quickly, the IGF Code is reviewed and updated periodically by the Organization. For this reason, an easily updated document containing the latest requirements is needed for the designers of the LNGPac^{TM}.

2.2 Classification societies

The classification societies date back to the middle of the 18th century when world trade was dependent on shipping. Lack of proper technology, controls and safety resulted in many ship losses and cargo suffered heavily. To minimize the loss of ships, an agreement was made by the financiers of the shipping business to establish safety requirements and regular inspections. This led to the creation of classification societies. (Wärtsilä, n.d.) In the maritime world today, there are many different classification societies. All classification societies base their rules on the IGF Code, with their own interpretations of it and with additional requirements. The purpose of the classification societies is to ensure that ships and their design are in accordance with international standards. During the design of, e.g. a marine fuel gas supply system, plans and information, including drawings, system plans, arrangements and different kinds of analyses, are to be submitted to dedicated classification society. The classification societies, however, are not only dedicated for the maritime industry. Many classification societies offer solutions and services for many different industrial sectors. Every ship is required to be registered under a state of choice. This is called a flag state and means that the ship is required to follow the law of the flag state it is sailing under. The classification societies are chosen according to what flag state a vessel is registered under.

The classification societies' rules are not necessarily set in stone. The rules are written in a way that there is room for discussion. During the design of a fuel gas supply system, problems may arise that need special treatment. If this occurs, and the set of rules applied do not clearly state what is required, a discussion with the classification society will be needed. The classification societies are well reachable as many of them operate all over the world.

Bureau Veritas, BV, is a classification society dated back to year 1828, founded to make the shipping industry safer. Today it is one of the world leaders in "*Testing, Inspection and Certification*". (Bureau Veritas, n.d.) BV is a worldwide organization, with its headquarters in Paris, France, serving 400 000 customers in 140 countries. BV do not only offer solutions in the maritime business, it also offers solutions and services in automotive, building, food and chemical markets etc. (Bureau Veritas, n.d.) BV's rules related to marine fuel gas supply systems are called ”*Gas Fuelled Ships*”. The latest version of these rules was released back in January 2017.

Det Norske Veritas Germanischer Lloyd, DNV GL, is a merger between two of the world leading classification societies, Det Norske Veritas and Germanischer Lloyd. The two independent organizations were founded in 1864 in Norway and in 1867 in Germany. As of 2013 they became merged, creating DNV GL and becoming the world's largest classification society for the maritime business. DNV GL also offers services in four other business areas. Those business areas are oil & gas, energy, digital solutions and business assurance. The DNV GL Group has its headquarters in Oslo, Norway. DNV GL has a vision to be ”*a trusted* *voice to tackle global transformations*”. (DNV GL, n.d.) The rules related to fuel gas supply systems published by DNV GL in 2019 are called ”*Gas fuelled LNG*”, found under DNV GL’s classification for ships in Part 6, Chapter 2, Section 5.

American Bureau of Shipping, ABS, is another large classification society that mainly offers classification services to a few different sectors of the industry. These are the maritime, offshore and gas industry. ABS was founded in 1862 with the purpose of setting standards for safety within the maritime business. Nowadays ABS is one of the biggest classification societies in the world, located in 70 countries. (American Bureau of Shipping, n.d.) The ABS rules concerning marine fuel gas supply systems were released in March 2016 and are called “*Propulsion and Auxiliary Systems for Gas Fueled Ships*”. This set of rules are not only an interpretation of the IGF Code. The rules are also based on another resolution written by IMO called ”*Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships*”.

Lloyd’s Register, LR, is the final classification society that will be mentioned. This is an organization established in 1760 as the world’s first classification society. LR was created with full focus on marine classification but today LR offers solutions and services in the maritime, energy, financial and many more industrial sectors. Updated rules written by Lloyd’s register are in general published every year. (Lloyd's Register, n.d.) Lloyd’s Register’s most recent set of rules containing requirements on fuel gas supply systems are called “*Rules and Regulations for the Classification of Ships using Gases or other Low-flashpoint Fuels*”. These were released in July 2019.

2.3 Area classification

A method used to classify and analyze where an explosive atmosphere might arise is called area classification. Design and use of electrical apparatus have caused severe accidents in the past. As a result of the safety problems, area classification is needed for the right selection of equipment and installation of equipment to reduce the risk for explosions. (Leroux, 2012)

Based on the frequency of existence and duration of an explosive gas atmosphere, hazardous areas can be classified into zones.

- Zone 0: “An area in which an explosive gas atmosphere is present continuously or for long periods”;

- Zone 1: “An area in which an explosive gas atmosphere is likely to occur in normal operation”;
- Zone 2: “An area in which an explosive gas atmosphere is not likely to occur in normal operation and, if it occurs, will only exist for a short time.”

Areas that do not fall under any of these classifications, are classified as non-hazardous, or safe areas. It is defined as ”*an area in which an explosive gas atmosphere is not expected to be present in quantities such as to require special precautions for the construction, installation and use of equipment*”. (Health and Safety Executive, 2004) To minimize the risks of using gas as fuel, the hazardous areas shall be limited. The IGF Code and the classification societies declares what parts of the fuel gas supply system is classified as which zone. (Health and Safety Executive, 2004)

2.4 LNG

Liquefied natural gas, LNG, is a significantly more environmentally friendly fuel than fuel oil, which has resulted in reduction of emissions around the world. Natural gas is one of the fastest growing resource for energy. LNG is not a recent discovery as it has been used already for about 60 years. The LNG market grows rapidly because of a more economical production, transportation and storage of LNG. Australia and Qatar are the world’s biggest exporters of LNG. The amount of LNG shipped by Australia in 2019 was 77.5 million tons. (Toscano, 2020) As the LNG market has become broader, the LNG shipping sector is also evolving rapidly. To reduce greenhouse gas emissions, the shipping industry is acting and more and more newbuilds choose LNG as fuel. Statistics from 2019 state that more than 170 vessels are LNG-fueled and in operation. In addition to those already in operation, there are 184 LNG-fueled ships on order. (Schaps, 2019) (International Gas Union (IGU), 2019)

2.4.1 Characteristics

LNG has different properties depending on the reservoir source of the gas and how it is processed. LNG consists of 87 mole % to 99 mole % methane and it is both colorless and odorless. LNG is usually stored at a temperature below -162°C, since the boiling point of LNG is usually at around -162°C. LNG has a density that varies between 430 kg/m^3 and 470 kg/m^3. This is a relatively low density, half the density of water. Natural gas is compressed into its liquid state (LNG) for transportation, as it occupies less space as a liquid. (Mokhatab, Mak, Valappil, & Wood, 2014)

In its liquid form, LNG is not flammable. The vapors of LNG on the other hand, are flammable and explosive between 5% and 15% by volume in air. The 5% limit is called LEL, Lower Explosive Limit, and the 15% limit is called UEL, Upper Explosive Limit. This means that if the concentration of vapor from the LNG is below 5%, there is too little methane present for it to burn. If the vapor concentration is too high, over 15%, there is too little oxygen present for the vapors to burn. Figure 1 illustrates what LEL and UEL is for natural gas, but it also explains the philosophy of gas detection.

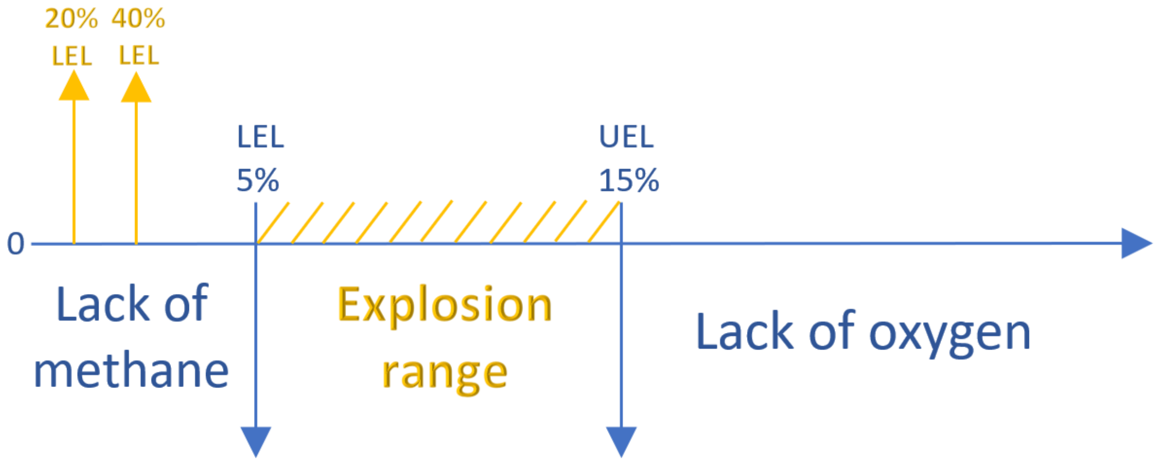

Figure 1. Explosion limits for natural gas.

2.4.2 Gas as fuel

Gas as fuel in ships is one of the most promising fuel solutions to meet the emission regulations. Natural gas is an encouraging option for shipowners when a newbuild is being planned. When natural gas is combusted, barely any sulfur oxides and nitrogen oxides are released, which is why natural gas is a clean energy source. It also generates low particle emissions and carbon emissions. Using LNG as fuel will reduce fuel costs compared to if marine gas oil would be used. (Sames, Clausen, & Andersen, 2011) When using natural gas as fuel, the most efficient way of storing it is in its liquefied form. Natural gas takes up about 600 times more space than LNG, which makes storing of the natural gas in its liquid state very efficient.

2.5 Nitrogen

Nitrogen, N_2, is a gas that is present to an amount of 78% in the air. Nitrogen can serve other purposes than providing for life on earth. Fuel gas supply systems are always equipped with a nitrogen generator to serve several purposes. Nitrogen is also referred to as inert gas. The purpose of inerting a system, or a part of a system, is to provide a non-combustible environment and to gas free desired part of the system.

One purpose of nitrogen usage is to cool down the tank and bunkering pipes before bunkering. An empty tank will have a relatively warm temperature, compared to the cryogenic LNG that will be bunkered. To keep the tank from warming up too much it is suggested that the fuel tank must never be completely emptied. If the tank would not be cooled down with nitrogen, thermal stress on the tank could occur. The nitrogen used to cool down the tank is supplied as cold nitrogen gas. By doing this, a temperature of about -100 °C can be reached in the tank which is safe enough for bunkering LNG. In some cases, the tank may be required to be cooled to an even lower temperature. This can be done by supplying liquified nitrogen. Nitrogen becomes liquid at a temperature of about -195 °C.

Another purpose nitrogen serve is to finish the procedure of emptying the tank. In this case it is warm nitrogen that is supplied into the tank to warm it up, which results in LNG vaporizing, thus emptying the tank. This is executed when the tank is emptied to a point that the LNG Pumps cannot pump any more LNG from the tank.

Nitrogen is also used for purging of bunkering pipes, but also for purging of other pipes inside the tank connection space. After bunkering it is important to get the bunkering pipes purged and cleaned from remaining LNG in the pipes. If a pipe section, e.g. between two tank connection spaces, would burst, it is important to get the pipe section purged to get rid of the LNG in the leaking pipe. By inerting different parts of the fuel gas supply system, dangerous situations can be avoided.

Nitrogen can also be used for transportation of LNG from one tank to the other. As warm nitrogen is supplied to the top of the fuel tank, the pressure inside the tank will rise. The outcome is that LNG will be pushed through the bottom connection of the fuel tank, into the other fuel tank, provided that the fuel tank pressure is lower in the tank where LNG is supposed to be transferred to.

One of the options of insulating a double walled pipe is to pressurize the surrounding pipe or duct with nitrogen. This type of double walled piping insulation is mainly implemented on the pipes that are penetrating the tank below the highest allowable liquid level. It is also frequently used to insulated bunkering pipes. Nitrogen can be supplied to double walled pipes at different pressures, depending on the circumstances.

2.6 LNGPac^{TM}

The LNGPac^{TM} is Wärtsilä's marine fuel gas supply system. It is a complete marine fuel gas storage and handling system designed and delivered by Wärtsilä. The intention of this fuel gas supply system is to store natural gas in its liquid state in a fuel storage tank, and when gas fuel is needed, the system will prepare and supply gas to the gas consumers. The LNGPac^{TM} can be applied to all kinds of ship types, such as cruise ferries, RoRo vessels and tugs. An LNGPac^{TM} is illustrated in Figure 2.

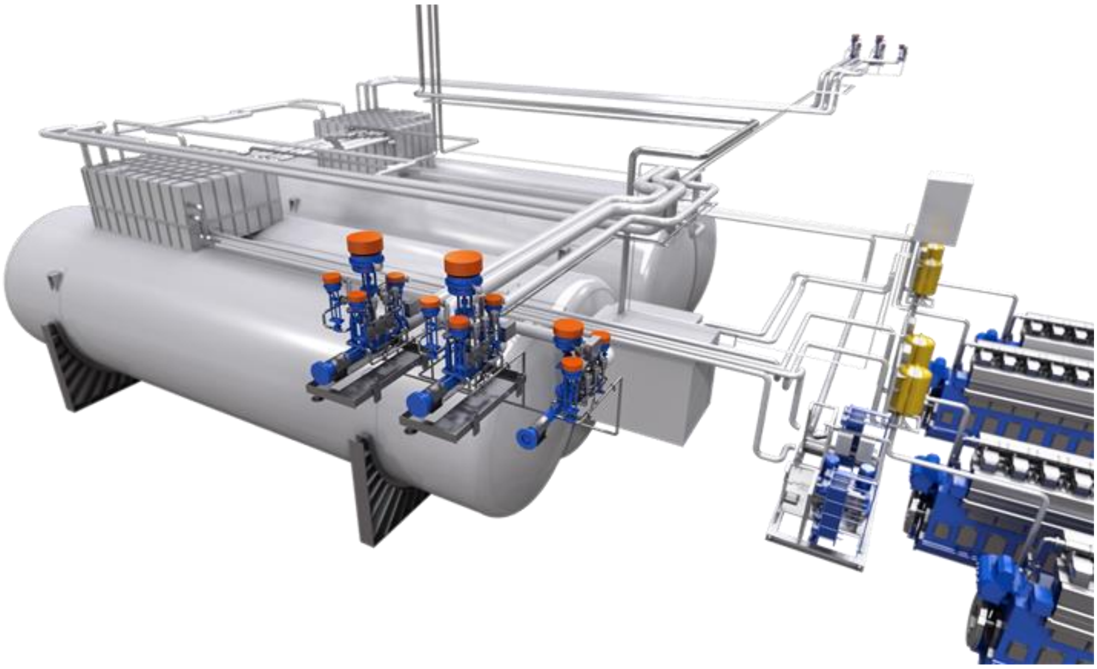

Figure 2. Illustration of an LNGPac^{TM}. (Wärtsilä, n.d.)

2.7 Marine Fuel Gas Supply System

A marine fuel gas supply system consists of several different parts. The numerous parts of a marine fuel gas supply system contain equipment serving different purposes. These spaces can be equipped with several types of equipment such as evaporators, compressors and pumps. The fuel storage tank can be of different types, with a variety of insulation materials and secondary barriers. Two common working principles for marine fuel gas supply systems are by supplying LNG by pumping it or with a pressure build-up system. These two types will be explained in more detail in Chapter 2.7.5 and 2.7.6. The LNG is stored in its liquid state, but it is consumed by engines as natural gas. This requires a heating process to vaporize the LNG to NG. The heat for vaporization of LNG comes from a heating media system. The consumers of natural gas are engines that run only on gas, or so-called dual fuel engines that also can run on fuel oil.

2.7.1 Tank types

There are several different tank types on the market. IMO has described two different basic tank types. The tank types are described as Membrane and Independent tank types. The different tank types have different approaches regarding the secondary barrier of the tank. The purpose of secondary barriers is not only to contain leakages through the primary barrier, but to isolate the tank in form of a liquid resisting outer element. A secondary barrier prevents the low temperature of the fuel from affecting the structure of the ship.

Membrane tanks are not-self-supporting, and the tanks are surrounded by the ship's hull structure. The membrane tank is required to have a complete secondary barrier, which is ensured by the ship's hull working as the outer tank. The membrane of this type of tank is a thin gas and liquid tight layer. The safety level, in case of a collision, is slightly lower for a membrane tank, as the damage caused by a collision can relatively easily be transmitted to the tank structure. Reliability is also an issue with membrane tanks because it is not easy to analyze the structure and discover fatigue failures. (Wärtsilä, n.d.; Mokhatab, Mak, Valappil, & Wood, 2014)

The other type is the independent tank. The independent tanks often have a spherical shape, but also prismatic. These tanks are divided into three categories. The independent type A tank, also called IMO Type A, is self-supporting. The Type A tank has a low operating pressure, less than 0,7 bar. The Type A tank is required to have a complete secondary barrier. The IMO Type B tank is required to have a partial secondary barrier. This type of tank is often used in LNG carriers and is, like Type A, non-pressurized. The last independent tank type is the IMO Type C. This is the type of tank that is most commonly used for the LNGPac^{TM}. This is a self-supporting, pressurized tank with an operating pressure below 10 bar. The Type C tank does not require a secondary barrier, but if there are pipe connections to the tank below the highest liquid level, which is often the case, a secondary barrier is required. (Wärtsilä, n.d.; Mokhatab, Mak, Valappil, & Wood, 2014)

The tank type that is most frequently used for marine fuel gas supply systems is the IMO Type C tank. It is designed either with or without a secondary barrier, depending on the tank penetrations. If the tank is fitted with a secondary barrier, good insulation is established with perlite and vacuum. If the tank has all pipe connections above the highest liquid level, the tank is designed single-walled with polyurethane insulation. The single-walled IMO Type C tank also requires the tank connection space to be separated from the tank. The differences between having a single-walled or double-walled are many. For example, the benefits of having a double-walled fuel tank is that the holding time is longer, a pressure build-up system is possible due to the allowance of bottom pipe penetration, the lifetime is longer, and the tank can be installed below deck. The benefits of a single-walled fuel tank are that it is cheaper, has a simpler structural construction and a higher volume is possible to achieve. (Wärtsilä, n.d.; Mokhatab, Mak, Valappil, & Wood, 2014)

2.7.2 Bunkering Station

The bunkering station is where fuel is transferred from an external source into the tank. The fuel can be transferred in its liquid or gaseous state, where the earlier mentioned is the common way of bunkering. The fuel can be bunkered in three different ways; truck-to-ship, terminal-to-ship or ship-to-ship. The different ways of bunkering come with different bunkering rates. Bunkering by a truck to ship setup will have a bunkering rate of about 40 m^3/h, while bunkering from a terminal to the ship will have e flow rate of about 500 m^3/h. A ship to ship setup would result in a flow rate between 150 and 200 m^3/h. Bunkering is required to be done in a safe manner. The piping between the bunkering station and fuel tank shall be safe and should not cause dangerous leakage. The bunkering stations can be designed with one or two pipes connecting the bunkering station to the fuel tank. If two pipes are connecting the bunkering station to the fuel tank, one pipe is used for the liquid transfer to the tank, meanwhile the other is used for returning the vapors from the tank to the supplier of LNG. The bunkering station can either be enclosed or semi-enclosed. Marine fuel gas supply systems are delivered with either one or two bunkering stations. If two bunkering stations are delivered, they are usually installed on portside and starboard side of the ship. The bunkering stations are equipped with valves, instruments and filters to ensure a safe transfer of liquefied natural gas into the fuel tank. A common way of arranging bunkering stations is to have it placed so that natural ventilation is sufficiently applied. Another option is to have the bunkering station arranged in an enclosed or semi-enclosed space. Depending on the arrangement of the bunkering stations, different regulations are applied.

2.7.3 Tank Connection Space

The tank connection space, TCS, is a gas tight enclosed space at one end of the fuel tank or on top of the tank. An enclosed space means that an explosive atmosphere will not be dispersed naturally. The tank connection space is where all tank connections, tank valves, other valves, instruments, evaporators, LNG pumps and piping are located. This space is intended to be able to safely handle a potential gas leak from the fuel tank. As it is a gas tight, enclosed space, all piping inside the tank connection space can be single walled. The tank connection space is always classified as a hazardous zone 1.

2.7.4 Airlock and Hatch Room

Access to the tank connection space must be through a bolted hatch. The space containing the bolted hatch will be classified as a hazardous area. To keep the tank hold space as a non-hazardous area and prevent direct access from a non-hazardous area into a hazardous area an airlock shall be installed. An airlock is a gas tight enclosed space that is a part of the tank connection space structure. The airlock is fitted with two self-closing gas tight doors to keep the hazardous area contained. Airlocks are not necessarily fitted only as access to a tank connection space. Other hazardous areas as bunkering stations, fuel gas preparation rooms or other fuel gas related spaces may be required to have access through an airlock. The requirements found related to airlocks do not only apply to the airlock related to a tank connection space, but to other hazardous area entrances as well.

2.7.5 LNG Pumps

An LNG pump is not a necessity for a marine fuel gas supply system. Many fuel gas supply systems though, do have LNG pumps, either one pump or two pumps. In these cases, the pump or pumps is the main way to supply fuel to the gas consumers. One option is to have an external pump placed in the tank connection space in a cryogenic sump with the sump’s inlet connected to the bottom of the tank. The sump is fitted with two outlets. One outlet would be a return line back to the fuel tank with the intention to return boil-off gas to the fuel tank. The other outlet is the pump feed of LNG from the fuel tank to the LNG supply line. An LNG pump can also be used for other purposes, e.g. to pump LNG from one tank to the other if cooldown of a tank is needed.

If the tank connection space is placed on top of the tank, there are two options of arranging the fuel pump. The first alternative is to place a submerged fuel pump inside the tank. Providing this solution, the pump with all its electrical components, is inside the tank allowing heat to be transferred to the LNG. This is a cheaper alternative to the other option, which is to have a deep well LNG pump inside the fuel tank. This means that the pump is inside the fuel tank, inside a caisson pipe, with its electric motor located inside the tank connection space. This allows for not having any electrical components, with the probability of releasing any heat, inside the tank.

The control of the fuel pump is done either locally or remotely. Remote control of the fuel pump is the common way of controlling the pump. The pump is then controlled automatically by a variable frequency drive (VFD). To keep the pressure from the pump steady, a PID-controller in the VFD determines the RPM of the motor. The set pressure of the PID-controller can be set by the operator. This setpoint is what gas supply pressure is desired. The PID-controller also needs feedback, i.e. what the actual pressure in the pipe after the pump is. This requires a pressure transmitter on the discharge line that gives a 4-20 mA signal to the PID-controller.

2.7.6 Pressure Build-Up System

A fuel gas supply system can be designed without an LNG pump. A setup without an LNG pump is called a pressure build-up system. This kind of system is suitable for gas consumers with an operating pressure below 6.5 bar(g) and for tanks with a small volume, below 500 m^3. The system is arranged with a so-called pressure build-up evaporator, PBE. LNG will naturally flow through the PBE, which is connected to the top of the tank. As LNG flows through the PBE and is returned to the spray shield at the top of the tank, the pressure inside the tank will increase. The increase of pressure will push vapors of LNG out of the tank at the top, and flow to the main gas evaporator, MGE, where it will be heated and supplied further in the system. This type of system is used on vacuum-insulated tanks.

2.7.7 Fuel Gas Preparation Room

A space containing compressors and evaporators for fuel gas preparation is called a fuel gas preparation room. LNG is pumped from the LNG tank, heated by the MGE and supplied to a fuel gas preparation room. In the fuel gas preparation room, the heated natural gas is supplied to the gas consumers. Having a fuel gas preparation room, allows for boil-off gas, BOG, to be consumed. BOG, which is cold natural gas, is supplied from the tank to a BOG-heater. From the BOG-heater the warm natural gas is supplied to the fuel gas preparation room. In the fuel gas preparation room, the natural gas is compressed to wanted fuel supply pressure and the final heating of the natural gas is done. After compression and heating of the natural gas, it is supplied to a buffer tank where it is mixed with the fuel supplied by the LNG pumps.

2.7.8 Heating Media System

Natural gas, supplied by the pump, is in its liquid state. In order to heat it and convert it to its gaseous state, an evaporator is needed. This is a device that heats and evaporates the LNG. The evaporator is installed in the tank connection space. The LNG enters the evaporator and gets heated by a heating medium circulating in the evaporator. In addition to an evaporator, a gas heater might also be needed. The gas heater is intended to heat boil-off gas from the tank, to the right temperature and then supply gas to desired destination.

The heating media system can be delivered as a separate skid installed in a non-hazardous area equipped with heat exchangers and circulation pumps. The heating media system consists of heat exchangers, one or several, that extracts heat from a source on the ship, e.g. engines' water-cooling system, to the heating medium which is a glycol-water mixture. The heating media system is also equipped with circulation pumps that make sure the glycol-water mixture is circulated through the evaporator and gas heater, allowing for regasification of the LNG.

2.8 Instrumentation

In order to make a process or a system run efficiently, effectively and safely, instrumentation is needed. A key part of meeting the safety requirements of IMO and classification societies is to have monitoring devices, or sensors. Sensors are used to measure process variables such as temperature, pressure, flow and levels. A sensor converts a physical property into some kind of electrical signal. Measurements from a process is sent to a control system that is programmed to execute a desired control action depending on what values it receives from an instrument. Several types of sensors providing digital and analogue measurements will be presented. The types of sensors to be presented are chosen from an industrial perspective.

However, installing a sensor alone in a process is not enough. To get a readable electrical signal, a transducer or a transmitter is needed. A transducer is a voltage- or current-output device, i.e. the energy received will be converted into a voltage or current output. The output signal can be sent in millivolts, volts or milliampere. A transmitter is a current-ouput device which converts the received energy into an international standard output signal of 4 to 20 mA. The reason transmitters are widely used in the industry is because a 4-20 mA signal is less affected by electrical noise than a voltage-output transducer's signal. Another advantage is that the 4-20 mA signal is less disturbed by the resistance in cables caused by long cabling distances. (ESI Technology Ltd, 2012)

The sensors and transmitters mentioned are analogue measurements. There are also measurements that are digital. Some process parameters that are measured generate digital output signals. This can for example be applied for monitoring of valves' positions, i.e. providing information about whether a valve is open or closed. A simplified example of the purpose of instrumentation is illustrated in Figure 3.

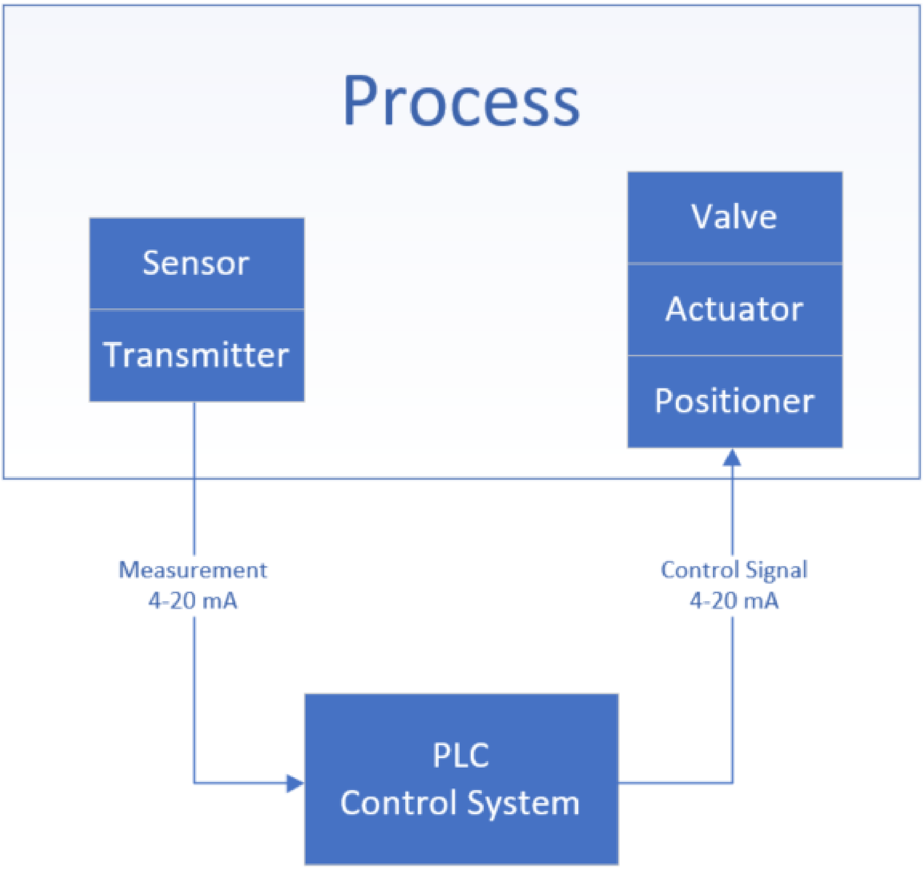

Figure 3. Simplified illustration of the purpose of instrumentation and control.

2.8.1 Temperature

A very essential part of industrial processes is temperature. It is therefore important that temperature is measured accurately. There are several different types of sensors that are used to measure temperature and a few of them will be described.

The most commonly used temperature sensor is called a Pt100. This is a platinum-based sensor that measures and indicates temperature by resistance change. By reading the voltage drop caused by changes in the sensing resistor, temperature can be measured. A Pt100 has a resistance of 100 Ω at the temperature 0°C. When the temperature rises, the resistance will begin to rise as well. This results in a resistance of about 139 Ω at 100°C. This type of temperature sensor belongs to a group called RTD, Resistance Temperature Detectors. A

Pt100 is also known as a PRT, Platinum Resistance Thermometer. The PT100 can have a 2-, 3- or 4-wired connection. If the sensor is setup with 2 wires, the resistance of the cable is added in the measurement. This will always show a higher temperature than what the actual temperature is. A 3-wire connection is less affected by the cable's resistance while 4-wire connections totally exclude additional errors. (Process Parameters, n.d.)

If the installation would require a 2-wire connection, a Pt1000 should be used. This type has a, more or less, same setup as the Pt100. The difference is that this type has a resistance of 1000 Ω at 0°C. In practice this means that the resistance in the cable will have a significantly lower impact on the accuracy of the measurement. (Peak Sensors, n.d.)

Another type of temperature sensor is a thermocouple, TC. The thermocouple consists of two wire conductors, made from different types of metal. These two wires are welded together at one end to create a junction. The junction is the point where temperature is measured. The change in temperature at this point will generate voltage. From the voltage generated, the temperature can be calculated. To get some reasonable use for a temperature sensor, a temperature transmitter is needed to convert the sensors signal to a stable 4-20 mA signal. (Waldemar, 2005)

If there is a temperature sensor in piping and instrumentation diagrams (P&ID), they are often referred to as TE, Temperature Element. However, industrial temperature sensors are usually combined and already installed together with a temperature transmitter and are in that case indicated as a TT, Temperature Transmitter, in P&IDs. If rules or standards require local reading of temperature as well as remote reading, the temperature measuring devices will be presented as a TIT, Temperature Indicator and Transmitter.

2.8.2 Pressure

Pressure is an important process variable that needs to be measured for not only safety, but for the functionality of processes. Pressure sensors are designed to convert physical pressure into an electrical output signal. There are three different types of pressure measurements. These are absolute pressure, gauge pressure and differential pressure. Absolute pressure is measured relative to zero pressure, i.e. vacuum. Absolute pressure is equal to gauge pressure plus atmospheric pressure. Gauge pressure is the difference between absolute pressure and atmospheric pressure. Differential pressure is a measurement between to points, e.g. pressure difference between the top and bottom of a tank. (Thomas, n.d.)

In industrial applications ceramic and metal pressure sensors are often used. A sensor with a ceramic process isolating diaphragm and a capacitive measuring cell measures change in capacitance at the electrodes of the ceramic carrier and the process isolating diaphragm as a result of change in pressure. Different parts of a process system may require different pressure measuring ranges. The thickness of the ceramic process isolating diaphragm will determine the range of the sensor. This type of pressure sensor is used in industries and has its benefits in form of long-term stability and accurate measurement. The capacitance change is converted to a 4-20 mA signal by a pressure transmitter. (Endress + Hauser, n.d.)

The other common industrial pressure sensor is built up with a piezoresistive measuring cell and a metallic process isolating diaphragm. This type of sensor requires a fluid in it. When pressure is applied to this type of sensor, the fluid will transfer the pressure from the metal process isolating diaphragm to a Wheatstone bridge. The bridge will cause an output voltage change that will be measured and translated into a 4-20 mA signal by the pressure transmitter. (Endress + Hauser, n.d.)

In a P&ID a pressure sensor is indicated as a pressure indicator, PI, which means the measured pressure is indicated locally. If the pressure is transmitted for remote reading it is indicated as a PT, Pressure Transmitter. A combination of these two is abbreviated as a PIT, Pressure Indicator and Transmitter.

2.8.3 Flow

There are several different ways of measuring flow in the process. A few flow measurement techniques used in industrial processes will be presented in this thesis. Flow of gases, liquids and steam are frequently measured in the industry. These can either be measured in mass flow rates (e.g. kg/s) or volumetric flow rates (e.g. m^3/s). Mass flow measurement is a more accurate way of measuring liquids or gases as it is not dependent of the physical properties of the liquid or gas. (Walton, 2017) Mass flow measurement is based on either the Coriolis principle or the thermal principle. Volumetric measurement can be measured electromagnetically or based on the vortex or ultrasonic principle. The electromagnetic flow measurement principle is not applied to flow meters measuring gas or cryogenic liquids, e.g. LNG.

The Coriolis flow measuring principle allows for direct measurement of mass flow. This is the technique used for the widest range of applications. Inside a Coriolis flowmeter is a measuring tube that will oscillate uniformly when there is no flow in the pipe. There are two sensors located on the inlet and outlet of the sensor that will register the constant oscillation at no flow. When the liquid starts to flow inside the measuring tube, additional twisting is imposed on the measuring tube’s oscillation. This is a result of the liquid’s inertia. The Coriolis effect will make the measuring tube to oscillate in different directions on the inlet and outlet of the tube at the same time. The sensors register the measuring tube’s change in oscillation with regard to time and space. The change in oscillation is called phase shift. The time delay between the phases is directly proportional to the mass flow rate which means that this is a direct measurement of how much liquid or gas is flowing through the tube. When the flow velocity increases, the measuring tube will give a greater deflection to the sensors. Density of the fluid can also be measured in a Coriolis flow meter. The sensors register the oscillation frequency of the measuring tube. A greater density of the liquid or gas will result in a less frequent oscillation of the measuring tube. (Endress + Hauser, n.d.; Walton, 2017)

The second type of mass flow measurement is based on the thermal flow measuring principle. Thermal mass flow meters are mainly used the measure flow of different gases and steam but not LNG. (Endress + Hauser, 2018) The flow meter in this case is equipped with two Pt100 temperature sensors. One of the sensors is used to measure the temperature of the liquid or gas in the pipe. This measurement is used as the reference temperature. Electrical energy is used to constantly heat the other sensor. The outcome of this kind of setup is that a pre-defined temperature difference is maintained. No flow in the pipe means no change in the temperature difference. As flow velocity increases in the pipe, the heated temperature sensor will lose its heat to the flowing liquid or gas. To maintain the pre-defined temperature difference, more heating current is needed in the heated temperature sensor. A higher flow means more heating current is required. The required heating current is proportional to the cooling effect and is a direct measurement of mass flow. (Endress + Hauser, n.d.)

The electromagnetic flow measurement principle is a widely used technology, measuring flow of conductive liquids. This is a volumetric flow measurement technique. An electromagnetic flow meter is set up with two field coils generating a constant magnetic field between them. Two electrodes are installed in the wall of the tube, which can detect electrical voltages. The conductive liquid inside the tube contain electrically charged particles. When there is no flow in the tube, the electrodes do not pick up any electrical voltages. As soon as liquid begins to flow, the magnetic field charges a force that will separate the positively and negatively charged particles. This generates an electrical voltage that is detected and measured by the two electrodes. The generate voltage is directly proportional to the flow velocity of the liquid. If the cross section of the pipe is known, the flow volume can be calculated. A greater flow velocity generates a higher electrical voltage. (Endress + Hauser, n.d.)

Another volumetric measuring technique is based on the Vortex principle. This is a technique suitable for flow measurement of LNG and gas. Inside the pipe of a Vortex flow meter, a bluff body is installed. This is a construction intended to disturb the flow and create vortices. After the bluff body, the pipe is equipped with a sensitive mechanical sensor that senses pressure differences in the liquid or gas. When there is no flow of liquid or gas, there are no vortices formed. When a certain flow rate is established, generation of vortices will begin. The vortices are detached alternately on either side of the bluff body and are directly proportional to the flow velocity. This results in a phenomenon called Kármán vortex street, i.e. zones of high or low pressure are created repeatedly downstream. The mechanical sensor will register these pressure differences. By counting the number of vortices passing the sensor, total flow can be calculated as the distance between two vortices corresponds to a defined volume of fluid. A higher flow in the pipe results in a higher measured frequency of vortex shedding. (Wilson, 2004; Endress + Hauser, n.d.)

A third technique that can be applied to measurement of LNG, gas and many other mediums is the ultrasonic flow measuring principle. (Endress + Hauser, 2018) This type of flow meter is equipped with pairs of sensors installed across to each other inside the measuring tube. These sensors can both transmit and receive ultrasonic signals simultaneously. The transit time, i.e. the time it takes for the ultrasonic signal to travel from the transmitting sensor to the receiving sensor, is measured. When an ultrasonic signal is received, a voltage is created. If there is no flow in the pipe, the transit time is equal in both directions. When the liquid or gas starts to flow, the transit time for the ultrasonic signals will be decreased in the direction of the flow and increased in the opposite direction. The difference in transit times measured by the sensors, is directly proportional to the velocity of the flow in the pipe. Increase of flow velocity will increase the differential transit time. Knowing the pipes cross section, the volume of the flow can be calculated.

Flow can also be measured by means of differential pressure. This a popular method for measuring different kind of flows that is also applicable for measurement of LNG or gas flow. (Endress + Hauser, 2018) The section of the pipe where differential pressure is supposed to be measured, an orifice plate is fitted that restricts the cross section. Two holes are located before and after the orifice plate in the pipe that are connected to the differential pressure sensor with two tubes. The tubes lead to two chambers that are separated by a diaphragm that will sense pressure applied to it. At no flow, the pressure will be equally big at both sides of the orifice plate. When the flow begins, the velocity on the orifice plate will increase and so will the pressure before the orifice plate. The pressure after the orifice plate will remain lower and thus, a pressure difference is sensed in the pressure chambers of the sensor. Higher flow in the pipe means greater pressure difference. This is a direct measurement of flow velocity and both mass and volumetric flow can be calculated. (Endress + Hauser, 2018)

2.8.4 Level

Accurate level measurement is of high importance for the safety of a fuel gas supply system. There are numerous different techniques to use for measurement of levels, therefore the most relevant techniques for marine fuel gas applications will be mentioned. In addition to continuous level measurement techniques, there is also a type of level measurement that will only switch the output signal at a certain point of level. This type of measurement is called point level detection.

Continuous level measurement can be established by installing a differential pressure transmitter connected to the top and bottom of a tank. Pressure of the liquid will be applied to the pressure chamber of the sensor through the connection at the bottom of the tank. The pressure above the liquid level is measured through the top connection into the pressure chamber. The transmitter will determine the level in the tank by calculating the pressure difference between the top and bottom of the tank.

Time-of-Flight is a method related to continuous level measurement. This technique can either operate with ultrasonic waves or with radar pulses. Piezoelectricity is the underlying technology for emitting ultrasonic waves. Radar pulses, or waves, are generated electromagnetically. Whichever type is used, its function is similar. The instrument emit waves or pulses continuously at a high frequency. The waves or pulses are deflected at the liquid’s surface, and then received by the sensor. If the tank geometry is known, the level of the tank can be calculated by measuring the time of flight, i.e. how much time it takes between emitting and receiving a pulse or wave. This is a direct measurement of the distance between the sensor and the liquid level. The waves or pulses can be emitted along a rod to the liquid, so-called guided radar measurement, or they can be sent out freely.

Point level detection can be achieved by installing a vibronic device. This is a sensor type based on a direct correlation between oscillation and damping in a medium. The sensor is a vibrating tuning fork. The tuning fork's oscillation is caused by excitement at the fork's resonant frequency. The oscillation system works piezoelectrically, either with a bimorph drive or a stack drive. The bimorph drive is set up with two discs connected to each other, one piezoelectric and one ceramic. The discs are compressed and expanded at different voltages, causing the fork to oscillate at an even frequency. A stack drive consists of several piezoelectric discs on top of each other, with changing polarization. By applying alternating voltage to the discs, they will start oscillating. The oscillation of the stack of discs, will cause a membrane to bend back and forth. As the membrane is bent to the outside, the tuning forks that are attached to the membrane, will be pushed apart. This results in oscillation of the tuning fork. When the liquid level rises and reaches the tuning fork, the frequency of the oscillating tuning fork will be reduced. The change in frequency is analyzed and results in a switching signal. This is a suitable option for detection of high or high-high level in a tank.

2.8.5 Positions

There are sensors dedicated for sensing positions of objects, in form of sensing if an object is present or not. The presence of an object is detected without making contact. This can be applied for sensing door positions, valve's positions etc. These kinds of sensors are called proximity sensors. Proximity sensors operate over a small range and that means they need to be installed close to the object which presence is intended to sense. There are many different types of proximity sensors. Two widely used types of these are inductive and capacitive sensors. A common type of sensor setup is to have a normally open or normally closed function, i.e. the sensor is in open state, with no current flow when no object is present and changes to closed state, allowing current flow when an object is sensed or vice versa.

An inductive proximity sensor is used to detect the presence of a metal object. It operates by supplying a current to an inductive coil at the end of the proximity sensor. By doing this, an electromagnetic field is generated. When a metal object is present, in front of the proximity sensor, the inductance of the coil will change caused by eddy currents being created. A change in the coil's inductance will switch the output signal of the sensor. (Shawn, 2019)

The capacitive proximity sensors have the ability to sense both metallic and non-metallic objects. Capacitive proximity sensors have a built-in plate, or conductive element, that generates an electrostatic field by being connected to an oscillator circuit. The second conductive element that is needed is the object that is intended to be sensed. When the object is present, the electrostatic field will cause a capacitance change, resulting in a rise of oscillation amplitude which is read by the sensor and an output signal is triggered. (Budimir, 2019)

2.8.6 Gas detectors

As for other instruments, gas detection can be based on several different principles. Today’s market offers a large amount of accurate and reliable gas detectors. The most common type of gas detectors is the catalytic sensor. Other types of gas detectors worth mentioning are infrared point gas detectors and open path infrared gas detectors.

The electro-catalytic gas detection sensors consist of a so-called bead, that is made of a Platinum wire coil that is electrically heated. The coil is covered with a ceramic base and the outer coating is a catalyst. This is the detector element of the sensor. When a combustible gas and air mixture passes the detector element, small combustions will occur, causing a temperature increase of the bead. This will also increase the resistance of the Platinum coil, i.e. the coil can be used as a temperature thermometer. The resistance change is measured and is a direct measurement of the gas concentration in the atmosphere. The measurement can then be presented on a display at what LEL percentage that atmosphere is. To allow combustions to occur, the sensor is installed behind a flame arrestor to keep the flames from the atmosphere where gas is present. The flame arrestor is somewhat decreasing the response time, but catalytic sensors are generally reaching the T90 value in 20-30 seconds. Honeywell defines the T90 value as ”*the time to reach 90 percent of its final reading*”. (Honeywell Analytics, 2013)

A second, very common type of gas detector is based on the infrared principle. An infrared point gas detector operates by emitting infrared light beams at two different wavelengths (dual wavelength). One of the wavelengths are set at the peak of absorption of the gas that is intended to be detected. The two sources of light are alternately emitted and passes through a measurement chamber where the sample gas is present. The emitted light is reflected into the unit through the sample gas. The strength of the signal of the emitted light beam and the returned light beam is compared and from the difference in signal strength, the gas concentration can be calculated. Infrared gas detectors have a faster response time (< 10 s) to gas than the catalytic sensors. Failure of an infrared gas detector will not act as if gas would be detected.

Another type of infrared gas detectors are the open path detectors. These are suitable for detection of gas in harsh environments where interference may be caused by fog, rain, dust or vibrations. Open path infrared detectors are set up with separated transmitters and receivers which allows for gas detection of the whole area between the transmitter and the receiver. The transmitter emits an infrared light beam that is received by the receiver. The gas that is present between these two components will interfere with the transmitted light beam and reduce the energy of the beam. The drop in energy is a measurement of the gas concentration in the area. This type of sensor has a faster detection of gas than the other mentioned gas detectors, typically with a T90 value of about 3 seconds. (Honeywell Analytics, 2013)

2.9 PLC

The brain of a process is the PLC, Programmable Logic Controller. This is a type of computer that is widely used in industrial automation systems. A PLC consists of three main components, a power supply, input and output modules (I/O) and the CPU. A basic overview of the components of the PLC is visualized in Figure 4. The power supply part is needed for running the PLC and to convert the power source (AC voltage) to usable DC voltages for other components of the PLC. PLCs have a current rating between 2 and 50 A, and this will directly affect the capacity of the PLC, i.e. a larger current rating would mean a more powerful PLC. (Cope, RealPars, 2018)

The Central Processing Unit, CPU, is the brain of the PLC system. The CPU communicates with the I/O modules and is intended to store, process and execute the software program that is sent to the PLC. The program that is transferred to the CPU is stored in a memory that will not lose the program if the power to the PLC is removed. If the CPU would stop working, the whole system would also stop.

I/O modules is to where instruments and other equipment are connected. There are both digital and analog input and output modules. The I/O modules are not required to be connected to the same rack as the PLC. There is also the possibility to install the I/O modules remotely. The I/O modules would then communicate with the PLC with data cables, through desired communication protocol. As an example, an analog input module would receive input values between 4 and 20 mA from analog measuring devices, such as pressure and temperature transmitters. The PLC is programmed to execute certain actions depending on the value of the received input. For example, an analog input of 18 mA from a pressure transmitter would mean that the pressure is very high where it is measured. The PLC could be programmed to activate a digital output upon receiving a signal that high. The digital output signal would be connected to a digital output module, which would send a 24 V signal to energize a solenoid that would let air flow to a pneumatic valve to close it.

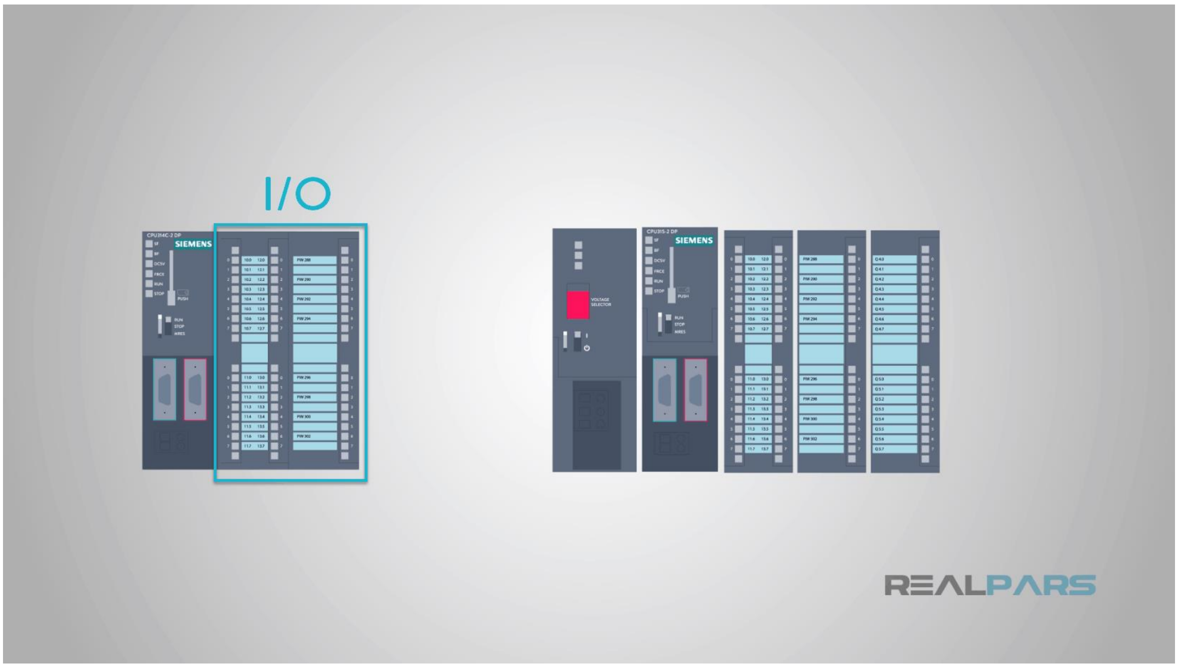

Figure 4. Basic parts of a PLC. (Richardson, 2018)

2.10 HMI

To get an overview of a process, a Human Machine Interface (HMI) is needed. This is a screen that is used to control and monitor process variables. An HMI, in other words, is an operating panel with a monitoring screen. Nowadays, HMIs are often touch screens, but normal screens working as HMI are still frequently used. The purpose of an HMI is to allow operators to both monitor the process and control the process. Information from sensors such as temperature, pressure, levels and flow, can be indicated remotely on an HMI screen. HMIs are custom programmed to be as user friendly as possible and to be compatible with the process where it is intended to operate. In order to have a working HMI, it needs to be compatible with the PLC that controls the process. The communication between the PLC and an HMI is established through different protocols or industrial networks, either Modbus, Profibus or Ethernet/IP. (Cope, RealPars, 2018)

3 IMO and classification societies' requirements

The IGF Code contains the minimum requirements on equipment and instrumentation for marine fuel gas supply systems. Classification societies' interpretation of the IGF Code might not include all requirements stated in the IGF Code. If that would be the case, the IGF Code still needs to be followed as it is the source of the classification societies' rules. The requirements found in all these rules are not set in stone. Some rules may be discussed and determined on a case to case basis. Other, equivalently safe designs and solutions to those mentioned in the rules are possible to get approved by classification societies. To get some sensible structure of the regulations demanded by these five set of rules, the IGF Code's requirements will be presented first and if classification societies have further requirements, they will be presented right after the IGF Code's requirements.

The automation system of the fuel gas supply system is required to be provided with a safe and reliable setup of monitoring, control, alarm and shutdown systems. The gas control system, or process control system, is intended to handle monitoring of parameters, initiation of alarms, and control of the process. As per chapter 15.2.4 of the IGF Code, the gas safety system shall be a dedicated system, independent of the gas control system, that handles safety functions. When needed, the safety system shall be able to shut down the fuel gas supply system. It is also stated that the safety system is intended to shut off the fuel gas supply to gas consumers. One reason for that safety actions is needed as a separate system is to avoid simple failures in the control system from affecting the safety of the system.

There are two types of different machinery spaces referred to in these rules. One of them is an ESD-protected machinery space and the other is a gas-safe machinery space. The ESD-protected machinery space does not have a complete double-walled fuel pipe arrangement, which means that a single failure can make the machinery space a hazardous area, even if it is classified as a non-hazardous area during normal operation. If the machinery space is ESD-protected, ESD arrangements are to be made in case of dangerous gas concentrations. All fuel piping in a gas-safe machinery space is in gas tight enclosures. This means the pipes are just about double walled all the way to the combustion chamber. If the machinery space is of gas-safe type, a single failure cannot lead to gas release into the machinery space. These two types of machinery spaces will have slightly different requirements.

A few general guidelines to follow when designing a marine fuel gas supply system can be found in the IGF Code and the classification societies rules, such as a leakage should not lead to an intolerable loss of power, the fuel containment system should not cause any damage to other structures on the ship due to cryogenic leakages and leakage on pipes are required to be rapidly detected. Other issues like containing leakages shall also be considered in the design of a fuel gas supply system. The control system of a fuel gas supply system must be designed to keep all process variables within acceptable limits.

(International Maritime Organization, 2015)

3.1 Process instrumentation

A marine fuel gas supply system is required to have monitoring of the process. The process instrumentation is needed for alarming when process variables are not kept within acceptable limits. The rules and regulations specify where instrumentation related to process monitoring is needed. The monitoring can be divided into sections, such as instrumentation for bunkering station, tank connection space and fuel gas preparation room. Included in process instrumentation are different kinds of temperature, pressure and flow measurements. The alarms that are required to be activated, are seen and heard on HMIs where control of the process is handled, e.g. on the bridge and in the engine control room.

3.1.1 Bunkering station

The IGF Code requires the bunkering stations to be equipped with drip trays due to the risk of gas leakage during bunkering. A drip tray is needed to protect the surrounding hull or deck structure in case of gas leakage. Further requirements on the drip tray is not found in the IGF Code but in the classification societies' rules. BV comments that a temperature sensor must be installed for leakage detection, and the safety system shall be activated in case it senses low temperature. The safety system is required to close the two stop valves on the bunkering and vapor return line. LR has a similar interpretation except for that the temperature sensor only must activate an audible and visual alarm at the bunkering control location, which in most cases is the ECR. The temperature transmitter for the drip tray is not mentioned in the ABS nor the DNV GL rules.

In the IGF Code it is stated that pressure between ship's manifold valves and the hose connections to shore must be indicated locally. This means pressure indicators on both the liquid bunkering line manifold and the vapor return line manifold. This statement has no further actions according to LR, ABS and DNV GL. BV adds that the LNG manifold pressure, not vapor return manifold, should also be indicated remotely which adds a transmitter to the required pressure indicator. The spot for measurement is described differently in the rules, such as manifold pressure, LNG manifold and the points between the ship’s stop valves and hose connections to shore.

Local pressure indicators on both liquid and vapor fuel manifold is required by the IGF Code. The only classification society that has additional requirements is LR that states that the high pressure on the bunkering line shall give an alarm and a bunkering shutdown, which will require a pressure transmitter, not just a pressure indicator.

An important part of the bunkering stations is nitrogen supply. Nitrogen is used to purge the bunkering pipes and the nitrogen supply needs to be monitored. Double block and bleed valves are required to be installed related to nitrogen supply to bunkering stations. Double block and bleed valves are set up as two valves in series with a venting valve between them that allows for pressure release. The functionality of the double block and bleed valves require pressure transmitters before and after the valves. This is not stated in any set of rules except for DNV GL’s rules. The pressure transmitters needed for double block and bleed valve functionality are further explained in Chapter 3.1.3. (International Maritime Organization, 2015) (Bureau Veritas, 2017) (Lloyd's Register, 2019) (American Bureau of Shipping, 2016) (DNV GL AS, 2019)

3.1.2 Tank monitoring

The fuel tank is required to be equipped with quite a few monitoring devices. The fuel tank level must be continuously read whenever the tank is in operation. An indirect level measuring device, e.g. differential pressure transmitter can be used for this purpose. This is required by all set of rules. In addition to level measurement, overfilling is required to be prevented. A high-level alarm is required by the IGF Code that works independently of other level measuring devices. This requirement is fulfilled by installing a temperature transmitter that will trigger the high-level alarm. As the LNG level is rising in the tank and gets closer to the temperature transmitter, the temperature will drop and when a set point of temperature is reached, the alarm will be activated. A radar instrument or a level switch can also be installed for this purpose. DNV GL specifies that the high alarm shall be triggered at about 95% volume of the tank, but it does not specifically say that the alarm shall be triggered by an independent sensor. Additionally, an independent sensor preventing the tank from becoming liquid full, i.e. high-high level alarm, shall be provided. This is often realized through another temperature sensor activating the safety system for closure of valves that also prevents the bunkering line from suffering too high pressure. There is also an option to use for example an ultrasonic level switch for activation of the safety system at high-high level. BV specifies that the tank inlet valve shall close, while ABS states that the bunkering manifold valves shall automatically close, and the bunker supply pump must stop. LR requires a bunkering shutdown when the high-high level is reached. DNV GL demands different actions on the high-high level alarm depending on during what scenario the high-high level is reached. If bunkering is ongoing and the high-high alarm is activated, the bunker connection valves must close. If the high-high level is reached when transferring LNG from one tank to the other, the tank valves must close.

For tank arrangements where all tank connections are above the highest allowable liquid level with the tank connection space on top of the tank, the differential pressure monitoring of the tank is not possible. This applies mainly for tanks without a secondary barrier. For continuous level measurement in these cases, a radar instrument can be installed. This is a more precise way of measuring the liquid level than the differential pressure measurement. To fulfill the requirement of having an independent measuring device activating the high-level alarm, a second radar instrument could be installed.

Low level and low-low level detection in the fuel tank is intended to alarm and automatically shut down and protect the LNG pump. This can be handled by the LNG pump’s VFD. The VFD will detect dry-running and give an alarm at one point and stop the LNG pump at another point. Another usual way to arrange this is by having a pressure transmitter installed on the pump’s discharge line. The pump’s discharge pressure, i.e. the value received from the pressure transmitter, and the set pressure for the pump can be compared to each other to get a pressure difference. If this pressure difference would become bigger than a specified value, the tank level is low, and this should trigger an alarm. The automatic shutdown at low-low tank level is accomplished by another pressure transmitter initiating the shutdown at a bigger pressure difference. The alarm for low tank level could also be achieved by installing a level switch on the pipe that is connected to the bottom of the fuel tank.

The fuel tank pressure is required to be monitored locally but also remotely at the bridge or ECR. A high-pressure alarm is demanded by the IGF Code and if the tank is vacuum insulated, a low-pressure alarm is also required. BV adds that if the fuel tank is of Type C, with pressure build-up system, the low-pressure alarm is needed. In addition, BV requires a high-pressure alarm that also activates closure of the tank inlet valves and stops the LNG pump. This results in an additional pressure transmitter for activation of the safety system. LR has an additional requirement that a bunkering shutdown shall be activated in case of high or low pressure in the tank, which also requires an additional pressure transmitter. ABS requires a high pressure shutdown of the bunkering manifold valves. The pressure alarms and shutdowns must be triggered at a pressure below the setpoint of pressure relief valves.

The temperature of the fuel tank, other than Type C vacuum insulated tanks, is required to be measured and indicated at three points of the tank. One temperature sensor at the bottom, one in the middle and one at the top, below the highest liquid level allowed. The IGF Code does not demand any actions, but it is required that tank temperature must be visible from a safe location where control of bunkering is possible. This requires temperature transmitters on all three temperature measurements. LR requires an alarm to be given at high temperature in the tank, which should be trigger by high temperature sensed at the bottom of the tank. The alarm is required to operate whenever the tank is in operation. LR also requires the vapor space of the fuel tank to have temperature monitoring. Since the temperature sensor at the top is required to be installed below the highest liquid level, a fourth temperature sensor needs to be fitted above. ABS has additional requirements when it comes to fuel tank temperature monitoring. Both high and low temperature in the tank is required to give alarms. These alarms shall be triggered by the temperature transmitter at the bottom of the tank. ABS does not mention that tank temperature shall be monitored remotely which allows for local temperature indicators in the middle and at the top of the tank.

When the fuel tank is constructed with a secondary barrier, leakage in the space between the primary and secondary barrier is required to be detected. As the fuel tank is insulated with vacuum, leakage detection can be fulfilled by installing a vacuum drop-off disc. This is a disc that is held in place when the space between the barriers is insulated with vacuum. If one of the barriers fails, the vacuum will be lost causing the disc to move from its correct position. A position sensor is installed to detect when the disc is moved from its position, resulting in desired actions. ABS is the only classification society that requires an alarm to be activated upon leakage. It is specified in the ABS rules that leakage from the primary barrier shall be detected, but when the vacuum is monitored, leakage from the secondary barrier would result in an alarm as well. (International Maritime Organization, 2015) (Bureau Veritas, 2017) (Lloyd's Register, 2019) (American Bureau of Shipping, 2016) (DNV GL AS, 2019)

3.1.3 Tank connection space

The tank connection space is intended to be able to contain any leakage of gas into the space. In case of leakage in the tank connection space, the leaked LNG will make its way to the bilge well. To detect the leakage, the bilge well is required to be fitted with a temperature sensor and a level indicator. All societies agree with the IGF Code that the level indicator is needed to give an alarm at high level, and the temperature sensor must give an alarm and an automatic shutdown of valves at low temperature. All societies require the tank valves to close, while DNV GL states that necessary valves need to be closed. BV and LR declares a level switch as the type of level indicator to use.

As per chapter 15.4.6 of the IGF Code, all pump discharge lines are required to be provided with a local pressure indicator. This is also mentioned in all classification societies' rules. This requirement is already covered by installing the pressure transmitter for LNG pump functionality and low tank level monitoring. ABS has additional requirements for the LNG pump's discharge line. One pressure transmitter is needed for activation of high- and low-pressure alarms, and a second pressure transmitter is needed for activation of the safety system at high-high pressure on the discharge line. ABS require monitoring of the inlet pipe to the LNG pump. High and low temperature alarms are demanded. These alarms are triggered by a temperature transmitter. A second temperature transmitter is needed on the same pipe for shutting down the system at high-high temperature.

The airlock has its own set of requirements. It is required to be fitted with two self-closing gas tight doors. The door positions need to be monitored to get visual and audible alarms at required scenarios. A statement found in chapter 5.12.5 of the IGF Code, says that a visual and audible alarm shall be activated if both airlock doors are open. The alarms must be provided on both sides of the airlock, i.e. an alarm horn and a visual warning light must be installed inside the airlock and outside the airlock. The same requirement is mentioned in all classification societies' rules. This is an example of a rule that is discussable as classification societies may accept an alarm horn on only one side of the airlock, provided that the alarm is heard both on the inside and outside of the airlock. To get these alarms, two position sensors, one per door, need to be installed that will sense the presence of the doors. The ABS rules do not contain these requirements, but a chapter in the "*Steel Vessel Rules*" are referred to, where the same statement as in the IGF Code can be found.

DNV GL is the only classification society that has a requirement for valve position indication. All automatic and remotely controlled valves' positions shall be indicated at the control location to indicate whether the valve is open or closed. This requires two position sensors on every automatic valve in the tank connection space.

Regarding the inert gas system, that provides nitrogen to the fuel gas supply system, the IGF Code and the classification societies require double block and bleed valves on the nitrogen supply line. DNV GL’s rules are the only set of rules that have specified control arrangement of the double block and bleed valves. The preferred way of controlling these valves according to DNV GL is by measuring differential pressure. This means that two pressure transmitters, one before and one after the block and bleed valves shall be provided. These measurements can be compared by the PLC, and when the pressure at the outlet of the block and bleed valves gets too low compared to the inlet pressure, i.e. a differential pressure of a certain value, the valves shall open.

Heating of the LNG is required to be monitored in a few different ways. Neither the IGF Code, BV or LR barely mention any regulations related to the process of heating LNG. In these three set of rules it is demanded that abnormal gas pressure in the gas supply pipe must give an alarm. This is most likely to be interpreted as a pressure transmitter on the outlet pipe of the evaporator is needed. Depending on how abnormal is defined, alarm levels shall be specified. In addition to the abnormal gas pressure, abnormal temperature alarms are required by BV. This is fulfilled by installing a temperature transmitter to measure the gas temperature on the outlet of the evaporator. ABS and DNV GL though, contain a bit more extensive set of requirements on instrumentation related to evaporators. ABS require the temperature of the LNG entering an evaporator to be monitored. Too high or low temperature on the LNG must activate an alarm. This requires one temperature transmitter on the pipe entering the evaporator. An additional temperature transmitter is needed to activate the safety system at high-high temperature of the LNG. The gas filled outlet pipe of the evaporator is also required to be monitored according to the ABS rules. Both temperature and pressure monitoring are needed. A pressure transmitter is required to measure the pressure on the outlet pipe and alarm if the pressure gets too low or too high. An additional pressure transmitter, connected to the safety system, shall shut down the system if high-high pressure is measured. The same type of monitoring applies for temperature of the gas in the outlet pipe of the evaporator. One temperature transmitter must alarm at low and high temperature, and another temperature transmitter should shut down the system at high-high temperature.

DNV GL’s approach to monitoring of the heating process is similar to the approach made by ABS. DNV GL require the heating media temperature after the evaporators to be monitored. This requires a temperature transmitter to alarm at low temperature on the heating medium. The temperature of the gas on the evaporator’s outlet must be monitored as well. One temperature transmitter is needed to indicate the temperature remotely and alarm at low temperature. A second temperature transmitter is needed for activation of the safety system if low-low temperature is sensed. This input shall close valves that will stop LNG supply to the evaporator, but also the master gas fuel valves shall close. The fuel pump must also be stopped. (International Maritime Organization, 2015) (Bureau Veritas, 2017) (Lloyd's Register, 2019) (American Bureau of Shipping, 2016) (DNV GL AS, 2019)

3.1.4 Fuel gas preparation

Fuel gas preparation might take place in a dedicated fuel gas preparation room. A fuel gas preparation room may be required to be constructed with a bilge well, serving the same purpose as a bilge well in a tank connection space. If this would be the case, the same monitoring of the bilge well as for a tank connection space applies. The fuel gas preparation room may also be fitted with an airlock entrance. That would require the same airlock monitoring as for the airlock related to the tank connection space.

The IGF Code and classification societies state that pumps and compressors located in a fuel gas preparation room should be equipped with necessary instrumentation to provide a reliable functionality. In addition, there are two specified instrumentation requirements on components inside a fuel gas preparation room. If a fuel gas preparation room is part of the fuel gas supply system, compressors are fitted in this room. The compressors need monitoring of the fuel gas inlet and outlet pressure. The inlet pressure is required to activate an alarm at too low pressure, and the outlet pressure needs to be alarmed at both too high and too low pressure. ABS has a few additional variables to be monitored. First, the compressor’s inlet pressure needs to be alarmed at both high and low pressure, with an automatic shutdown at high-high pressure. This requires two pressure transmitters. The inlet temperature to the compressor is required to be monitored for too high temperature, resulting in an alarm if high temperature is reached. A second temperature transmitter is to be fitted with the intention to trigger a shutdown at high-high temperature. The compressor’s discharge line, or outlet pipe, shall be monitored with activation of alarms at too high or too low pressure, which is fulfilled with a pressure transmitter. If low-low pressure would be reached, an automatic shutdown must be triggered by a second pressure transmitter. The temperature on the outlet pipe of the compressor is demanded to alarm at too high or too low temperature and shut down if high-high temperature is achieved. To realize this, two temperature transmitters would be needed. ABS does not specify what kind of shutdown these unacceptable process variables should initiate. (International Maritime Organization, 2015) (Bureau Veritas, 2017) (Lloyd's Register, 2019) (American Bureau of Shipping, 2016) (DNV GL AS, 2019)

3.1.5 Heating media system

ABS and DNV GL are the only classification societies that include monitoring of some variables related to the heating circuit for providing heat to evaporate the LNG. The heating media system is by DNV GL required to have monitoring of heating media circulation. This means a flow transmitter located close to the heating media pumps must be provided to monitor the flow of the heating medium. The rules do not specify whether the alarm should be activated at too low or too high flow of the heating medium. There is another statement found in the DNV GL rules which demands an automatic stop of the fuel pumps and closure of the tank valves if the heating media flow would stop. To fulfill these requirements one flow transmitter connected to the safety system is enough. (DNV GL AS, 2019)

ABS has a slightly different approach to the heating media system monitoring. The expansion tank of the heating media system must be equipped with two level switches installed near the top and bottom of the tank to sense when the level is too high or too low. An additional level switch is needed for activation of an unspecified automatic shutdown at low-low level in the tank. One level indicator and transmitter, that handles the low and high alarms, could also be installed in lieu of the two alarming level switches. As mentioned earlier there is a pump working in the heating media system that ensures there is circulation of the heating medium through the evaporators. The pressure of the heating medium on the outlet of the pump(s), needs to be measured. The pressure transmitter on this pipe shall make sure activation of alarms occurs when the pressure drops too low or becomes too high. An additional pressure transmitter is required to initiate a shutdown at low-low pressure. The temperature of the glycol-water mixture entering the heating media system is also required to be monitored. Two temperature transmitters are needed for providing alarms at high and low temperature measurements, and a shutdown must be activated at low-low temperature. (American Bureau of Shipping, 2016)

3.2 Ventilation

Ventilation arrangements are an important part of safety for the fuel gas supply system. Ventilation of hazardous areas is required to be separated from ventilation of non-hazardous areas. Electric motors of ventilation fans and flow monitoring devices shall be classified for the same hazardous zone as the space it is ventilating. There are many requirements regarding ventilation monitoring and actions as double walled pipes may be arranged with air ventilation of the surrounding pipe or duct. These will however be presented in Chapter 3.3. In this chapter ventilation of different spaces, related to the fuel gas supply system, will be presented.

The tank connection space is classified as a hazardous zone 1 and will require a ventilation capacity of 30 air changes per hour. All set of rules require an alarm to be activated if required ventilation is lost. To get these alarms, flow switches are needed on the ventilation inlet and outlet serving the TCS. BV accepts a ventilation capacity below 30 air changes per hour if the gas concentration calculation for the TCS does not exceed 40% LEL. BV requires an additional action which is an automatic shutdown of tank valves if ventilation is lost in the TCS. This can also be found in DNV GL’s rules, with an additional output to shut down the fuel pump. ABS only adds that the TCS should be ventilated at under pressure. DNV GL requires the same type of ventilation as ABS. DNV GL also has a requirement that if one fan serving the tank connection space fails, a minimum ventilation capacity of 50% needs to be maintained. If a fan fails, a so-called reduced ventilation scenario occurs, which will, by DNV GL, require an alarm to be activated.

It is stated in the IGF Code that an overpressure ventilation of the airlock relative to the hazardous space, in this case the tank connection space, is required. Having the airlock ventilated this way, will result in air flowing into hazardous space when the door to the hazardous space is open. This is a method used to contain the hazardous area. If the under-pressure of the tank connection space relative to the airlock is lost, alarms must be activated and access to the space is not allowed until the ventilation is reinstated. In addition, alarms must be activated if one of the airlock doors are opened during loss of under-pressure ventilation. To monitor the over- and under-pressure ventilation, two pressure transmitters are required. One pressure transmitter will monitor the airlock pressure, and the other will monitor the pressure inside the tank connection space. The PLC should be programmed to compare these two parameters and activate an alarm when the pressure difference between the two spaces falls below a set value. The pressure transmitters are required by all set of rules. BV mentions that a differential pressure monitoring system is required and specifies that the pressure difference must not be below 25 Pa, or 0.25 mbar.

A fuel gas preparation room is also required to have 30 air changes per hour as minimum ventilation, but the space is to be ventilated at under pressure. The space is required to be ventilated when pumps or compressors are in operation. In case of a failure of one ventilation fan, the ventilation capacity must not fall below 50%. ABS has a stricter requirement for the fuel gas preparation room, which is that the ventilation capacity shall not be less than 100% if one fan is out of service. Loss of ventilation in a fuel gas preparation room must also activate an alarm, which requires two flow switches, one on the ventilation inlet and one on the ventilation outlet. DNV GL adds activation of an alarm at reduced ventilation in the fuel gas preparation room. The only classification society requiring safety actions upon loss of ventilation in a fuel gas preparation room is DNV GL. They require valves to be closed that isolates the fuel gas preparation room and pumps and compressors must be stopped.

Regarding enclosed or semi-enclosed bunkering stations' ventilation, the IGF Code states that it "*shall be subject to special consideration within the risk assessment*". The IGF Code requires that any loss of required ventilation must activate a visual and an audible alarm. This requires flow switches on the ventilation inlets and outlets of the tank connection space and fuel gas preparation room. For enclosed or semi-enclosed bunkering stations, BV's set of rules are the only that requires an alarm and shutdown of the bunkering valves upon loss of ventilation. BV also requires bunkering stations to have a minimum of 30 air changes per hour ventilation capacity. The rest of the classification societies do not have any additions.

Machinery spaces are required to have an independent ventilation system. ESD-protected machinery spaces are by the IGF Code required to have efficient ventilation with a capacity of at least 30 air changes per hour. There is an alternative, which is to have a ventilation with 15 air changes per hour during normal operation but upon gas detection, the ventilation would automatically increase to 30 air changes per hour. Failure of one fan must not lead to a ventilation capacity reduction of more than 50%. Loss of ventilation in an ESD-protected machinery space shall activate an alarm and a shutdown of gas supply to the machinery space shall be initiated. ABS has different requirements for ESD-protected machinery spaces. Failure of one fan ventilating an ESD-protected machinery space, must not lead to any reduction of ventilation capacity, i.e. it should stay at 100%. ABS also states that the shutdown should close the master gas fuel valve and activate the block and bleed valve. This means installation of flow switches connected to our safety system is required. Activation of the double block and bleed valve is required by DNV GL too. DNV GL adds that an alarm is required if the ventilation of an ESD-protected machinery space would be reduced.

The IGF Code does not contain any ventilation requirements for gas-safe machinery spaces. The ABS rules include one statement which is that more than 50% ventilation capacity is required in case a fan serving a gas-safe machinery space fails. ABS is also the only society that has made a statement about ventilation of a tank hold space. A ventilation capacity of six air changes per hour is required for a tank hold space containing a vacuum insulated Type C tank or a single shell Type C tank.

Regarding means to confirm ventilation capacity, LR defines acceptable means as monitoring of ventilation electric motor combined with under pressure indication, monitoring of ventilation electric motor combined with ventilation flow indication or just monitoring of ventilation flow rate. (International Maritime Organization, 2015) (Bureau Veritas, 2017) (Lloyd's Register, 2019) (American Bureau of Shipping, 2016) (DNV GL AS, 2019)

3.3 Double walled pipes

Double walled pipes are required for safe operation of a fuel gas supply system. There are three different ways of arranging double walled pipes. The pipes can be vacuum insulated, air ventilated or pressurized with inert gas. The annular space between the inner and outer pipe is needed to be monitored, because a change in measured parameters would indicate a leakage. Chapter 13.8 of the IGF Code includes general requirements for double walled fuel pipes. Ventilation of the annular space of a double walled pipe is required to have a capacity of at least 30 air changes per hour. The ventilation can be reduced if a minimum flow velocity of 3 m/s is guaranteed. DNV GL adds to ventilation of secondary enclosures that if one fan fails, the ventilation capacity must not fall below 50%.

Marine fuel gas supply systems are commonly designed with vacuum insulation on cold pipes, e.g. bunkering pipes, tank penetration pipes and interconnection pipes related to bunkering. The IGF Code does however not contain any specific regulations regarding vacuum insulated pipes. Double walled pipes insulated with pressurized nitrogen are only mentioned in one chapter, which says that if inert gas is used as part of the leakage detection system, means must be provided to monitor the quantity of gas supplied to those spaces. The outer pipe or duct must however be designed to withstand higher pressure than the working pressure of the gas piping inside.

There are no specific regulations for arranging e.g. bunkering pipes with vacuum insulation or double walled pipes insulated with pressurized nitrogen between the tank connection space and machinery space. In practice, the option of providing a solution equivalently safe, stated in chapter 9.6.1.3 of the IGF Code, applies to other gas piping as well. For that reason, additional monitoring devices other than those explicitly described in the rules, will be presented. The DNV GL rules, however, do include a statement that says monitoring of leakage on double walled pipes containing cryogenic liquids is required. (International Maritime Organization, 2015) (DNV GL AS, 2019)

3.3.1 Insulation Failure

The first double walled pipes that will be covered in this chapter are pipes that penetrate the tank. Tank connections are in some cases fitted below the highest allowable liquid level. As per chapter 6.3.9 of the IGF Code, that kind of piping requires a secondary barrier up to the first valve. Regarding this point, a secondary barrier is not specified as a double walled pipe. In the past, the secondary barrier up to the first valve could be arranged to have the same vacuum insulation as the tank itself. This would eventually result in problems related to leakage detection in that pipe. Through the years of development of fuel gas supply systems, the double walled pipe arrangement for pipes penetrating the tank below the highest allowable liquid level are preferred to be insulated with pressurized nitrogen. There are no clear statements for leakage detection on these pipes, except for DNV GL that requires leakage monitoring on both the inner and outer pipe. As the pipes are insulated with pressurized nitrogen, a suitable way of detecting a leakage would be with a pressure transmitter. A pressure transmitter is needed to monitor the nitrogen pressure supplied to the double walled tank penetrating pipes. If the nitrogen is supplied with higher pressure than the working pressure of the inner pipe, a leakage of the inner pipe would result in a pressure drop sensed by the pressure transmitter. In case of outer pipe rupture, there would be a drop to atmospheric pressure. If nitrogen is supplied with a pressure between the working pressure of the inner pipe and the atmospheric pressure, it can be determined which one of the pipes are leaking. Leakage in the outer pipe would lead to a pressure drop to atmospheric pressure while leakage in the inner pipe would result in a pressure rise as the pressure of the inner pipe is greater than the insulating pressure. Special considerations for tank penetrations below the highest allowable liquid level is not mentioned in the ABS rules.

Fuel bunkering pipes must not cause any dangerous leakage. The double walled bunkering pipes are by the IGF Code, required to alarm at loss of ventilation in the annular space. This means that the IGF Code only covers the option for air ventilated double walled piping arrangement for bunkering pipes. The rules say "*bunkering lines*" which means that the monitoring is needed both on the liquid bunkering line and the vapor return line. To monitor ventilation in a double walled bunkering pipe, a flow switch sensing air flow in the annular space is needed. In addition to the alarms, BV requires an automatic shutdown of the bunkering manifold valves. DNV GL states that leakage detection in the duct or outer pipe of the bunkering lines must close the bunkering valves. This statement is written in a way that it covers all types of insulation of pipes. Neither BV, LR or ABS mention any regulations about vacuum insulated or nitrogen pressurized double walled bunkering pipes. As marine fuel gas supply systems can be provided with either vacuum insulated, pressurized with nitrogen or air ventilated bunkering pipes, the other options also need to be presented. If the bunkering pipes are vacuum insulated, instead of measuring flow, pressure should be monitored. If the pressure sensor senses rise in pressure, i.e. loss of vacuum, there is a leakage either in the inner or outer pipe. Installation of two pressure transmitters, one on the bunkering line and one on the vapor return line is needed to get desired alarms and actions. The same actions as for air ventilated bunkering pipes is assumed to be needed for vacuum insulation failure. This is assumed since there is a note in a table of the IGF Code containing gas supply monitoring actions that requires the same actions for loss of inert gas over-pressure as for loss of ventilation in a double walled pipe in a gas-safe machinery space. The last option, to have the annular space pressurized with nitrogen, would also require pressure monitoring, in the same way as for the tank penetrating pipes. Loss of the nitrogen over-pressure is assumed to result in the same actions as for ventilation loss. However, providing a solution not specifically mentioned in these rules, the safety of the solutions will most certainly be required to be explained.

Chapter 9.5 of the IGF Code covers double walled piping outside of a machinery space that passes through enclosed spaces, e.g. fuel gas piping between a TCS and a machinery space. In this chapter it is stated that fuel gas piping is required to be inside an under-pressure, ventilated with 30 air changes per hour, pipe or duct. It is also stated that other equivalently safe solutions may be accepted, which allows for use of pressurized nitrogen as insulation, but there are no specific actions required. If the fuel gas supply pipes between the tank connection space and the machinery space are air ventilated, loss of ventilation in the annular space must result in an alarm and a shutdown of gas supply to the machinery space. There is an exception stated in the IGF Code and that is if the fuel supply pipes are separate for different engines, only automatic closure of the master gas fuel valve serving the pipe where ventilation is lost would be needed. BV has commented in chapter 9.5.1 about options of having double walled pipes either ventilated, vacuum insulated or pressurized with inert gas on fuel gas piping between the tank connection space and the machinery space. It is described in BV's rules that pressure sensors are needed to detect loss of vacuum between pipes if vacuum-insulation is used, followed by suitable alarms. A table in the BV rules containing gas supply monitoring, does however not include additional requirements on how to act upon insulation failures on pipes between the tank connection space and the machinery space. LR and DNV GL has an additional action to closure of the master gas fuel valve upon ventilation loss in a double walled pipe between the TCS and the machinery space and that is activation of the double block and bleed valve on affected pipe. According to LR, the alarms activated by ventilation loss, must also be given inside the machinery space. DNV GL also requires the tank valves to close. ABS states that gas supply pipes shall either be pressurized with nitrogen or be air ventilated, which will require either pressure transmitters or flow switches to detect leakage.

Chapter 9.6 of the IGF Code covers double walled piping inside a gas-safe machinery space. For a gas-safe machinery space the options are to have the fuel gas piping inside an under-pressure air ventilated pipe, or to have the annular space pressurized with nitrogen. If the double walled pipe is air ventilated there is an option to have a ventilation capacity of 10 air changes per hour instead of 30 air changes per hour, by filling the duct with nitrogen upon gas detection. There is also a third statement that allows for other solutions, provided that the safety level is equivalent. For double walled piping inside a gas-safe machinery space, the IGF Code has a couple of required actions. Upon loss of ventilation in the annular space of the fuel gas pipe an alarm and a closure of the master gas fuel valve isolating the failed fuel gas pipe is required. As stated in the IGF Code, loss of inert gas over-pressure in the annular space of the double walled pipe inside a gas-safe machinery space is required to lead to the same actions as for ventilation loss. LR adds to the ventilation loss that the fuel gas supply line's double block and bleed valve shall be activated, and the valve's position must be indicated at a control location. DNV GL require closure of the master gas fuel valve and activation of double block and bleed valve on the pipe where ventilation is lost. ABS includes in one of its tables the scenario of having pressurized nitrogen as insulation of the fuel gas supply pipes between the TCS and machinery space. Loss of over-pressure in the annular space of the double walled pipe should alarm and initiate a shutdown of the master gas fuel valve. (International Maritime Organization, 2015) (Bureau Veritas, 2017) (Lloyd's Register, 2019) (American Bureau of Shipping, 2016) (DNV GL AS, 2019)

3.3.2 Gas Detection

If double walled pipes are air ventilated, gas detection in the annular space is required. The double walled pipes between the tank connection space and a machinery space is required to be fitted with two detectors. The IGF Code and all classification societies demand activation of an alarm if a gas concentration of 20% LEL is detected on one of the gas detectors. If 40% LEL gas concentration is detected on two detectors, a shutdown of tank valves must be initiated. As the gas supply pipes are often totally separated for different machinery spaces, closure of the master gas fuel valve on the leaking pipe is enough upon gas detection on two detectors. Similarly, as for gas detection in different spaces, ABS does not specifically say that the safety system shall be activated after gas detection on two detectors. DNV GL is the only classification society that require both closure of tank valves and the master gas fuel valve, but there is a statement in another part of the rules that allows for necessary valves that will isolate the leakage to be closed. The vent valve between the master gas fuel valve and double block and bleed valves are also required by DNV GL to be opened.

The IGF Code and classification societies include the scenario of air ventilated bunkering pipes. If this is the case, gas detection is required, and an emergency shutdown must take place. What kind of emergency shutdown that is needed is only specified in BV’s rules, which says that a bunkering shutdown is demanded. It is neither stated at what gas concentration level the shutdown is intended to be activated nor how many detectors gas must be detected on. ABS though, says that the alarm point should be at 20% LEL and the ESD system needs to be activated upon 40% LEL gas concentration. This requirement is assumed to require one gas detector per bunkering pipe. DNV GL has a bunkering shutdown demand and isolation of bunkering pipes upon leakage detection on bunkering pipes. Due to this statement gas detection on the bunkering pipes is required.

Double walled piping inside a machinery space also require gas detection if the secondary enclosures are air ventilated. These pipes have a different gas concentration to be alarmed at. Gas detection at 30% LEL on one detector should activate an alarm. If a gas concentration of 60% LEL is detected by two detectors, the master gas fuel valve shall close on the pipe where gas is detected. DNV GL adds opening of the vent valve on affected pipe. (International Maritime Organization, 2015) (Bureau Veritas, 2017) (Lloyd's Register, 2019) (American Bureau of Shipping, 2016) (DNV GL AS, 2019)

3.4 Gas detection

For safe operation of a fuel gas supply system, gas detection is needed. This chapter will only contain gas detection requirements regarding different spaces, since the other gas detection related requirements found in the rules were explained in Chapter 3.3.2. The IGF Code requires alarms to be activated by gas detection on one detector, while the safety system must be triggered by gas detection on two detectors. The gas detectors described in this chapter are required to be permanently installed. The gas detectors shall be connected to a dedicated gas detection system. The gas detection system is connected to our safety system to give inputs for initiation of required shutdowns upon gas detection.

It is stated that the number of detectors each space is required to be fitted with depends on the layout, size and ventilation of the space. Nevertheless, to fulfill the IGF Code's requirements, at least two gas detectors in each space is needed. Detection on two detectors is needed for redundancy reasons. By this method, false emergency shutdowns are avoided. However, if self-monitoring gas detectors are installed, gas detection on only one detector is an accepted way of triggering a shutdown.

The philosophy of the gas detection is 2oo2 voting, which means that in order to activate the safety system, the gas is needed to be detected on two different detectors. It is defined in the rules that the amount of gas detectors is dependent on the size of the space, which means 2oo3 or 2oo4 voting might be required but the bottom line is that detection on two detectors is needed for activation of the safety system. DNV GL points out that a failed gas detector should be considered as an activated gas detector. The requirements for actions related to gas detection can be found in a table in the IGF Code. The goal of arranging a gas detection system is to stop gas supply to the space where gas has been detected.

The tank connection space is required to be fitted with two detectors. Gas detection on one of the gas detectors at 20% LEL shall activate an alarm, while 40% LEL gas detection on two detectors shall initiate a shutdown of the tank valves. In addition to closure of the tank valves, DNV GL requires pumps located inside the tank connection space to shut down upon gas detection. Gas detection in the fuel gas preparation room shall alarm at 20% LEL on one detector and cause a shutdown of valves to cut the gas supply to the room at 40% LEL on two detectors. DNV GL demands closure of the tank valves and shutdown of pumps and compressors in the fuel gas preparation room if gas is detected in that space. Airlocks are required to have one gas detector. Neither the IGF Code nor classification societies' rules include any safety actions for gas detection in an airlock. At what gas concentration the alarm shall be activated at is not specified but is assumed to be at 20% LEL. The glycol-water expansion tank is also required to be fitted with one gas detector with a non-specified alarm activation point. Gas detection in the airlock is not mentioned in the ABS rules.

An ESD-protected machinery space is required to alarm at 20% LEL on one detector and activate a shutdown of fuel gas supply to the machinery space where gas was detected at 40% LEL gas detection on two detectors. To shut down fuel gas supply, the master gas fuel valve needs to be closed and the double block and bleed valves inside the GVU shall be activated. In addition, all non-certified electrical equipment in the machinery space must be disconnected. BV only has one additional action on gas detection, which is that an automatic shutdown of the engines and other gas consumers shall be activated upon gas detection in ESD-protected machinery spaces. This addition is also found in the ABS rules. The ABS rules do not clarify if the requirement of activating the safety system after gas has been detected on two detectors is applied. DNV GL demands gas detectors inside a gas safe machinery space as well. It is not specified at what gas concentration the alarm shall be activated but it is stated that the detectors must be installed above the engine.

ABS and BV has more requirements related to gas detection than those mentioned in the IGF Code. Gas detection in bunkering stations is needed if the bunkering stations are enclosed or semi-enclosed, an alarm is needed at 20% LEL and a shutdown of bunkering manifold valves at 40% LEL. The statement that shutdowns shall be activated upon gas detection on two detectors is left out in the ABS rules. There is a requirement that the gas detection system must be of the self-monitoring type which means that if a system fault is detected, a false emergency shutdown will not be triggered. For these reasons, one detector without voting principles per space is accepted by ABS. DNV GL’s rules include a gas detection alarm in the bunkering station, depending on the arrangement of the bunkering station. All set of rules also mention that a tank hold space containing a fuel tank other than type C, shall be fitted with a gas detection alarm. No other set of rules than DNV GL’s rules mention that the alarm should be activated at 30% LEL. (International Maritime Organization, 2015) (Bureau Veritas, 2017) (Lloyd's Register, 2019) (American Bureau of Shipping, 2016) (DNV GL AS, 2019)

3.5 Fire detection

As for the gas detection system, the fire detection system is arranged as a dedicated system handling the fire safety of the fuel gas supply system. When it comes to fire detection the requirements found are, especially in the IGF Code, quite few. Different types of systems such as water spray systems and powder fire-extinguishing systems are somewhat well explained in the IGF Code, but when it comes to fire detection there is not much required. The chapters about fire safety include many references to regulations written by SOLAS and another set of rules called Fire Safety Systems Code. These rules will not be studied for this thesis. Therefore, a not too complex explanation of fire detection requirements will be provided. It is not explained how many fire detectors that is needed for different spaces, but various spaces are classified according to SOLAS regulations, which most probably also include how to determine the number of detectors. For example, it may be stated in the rules that a tank connection space is classified as a machinery space of category A. To understand what this would mean for fire detection, other rules and regulations would be needed to be studied.

Fire detection in a tank hold space is mentioned in the IGF Code. Activation of an alarm shall be ensured if fire is detected in a tank hold space. Any requirement to fire detection in a tank hold space cannot be found in the ABS rules. The ventilation trunk that serves the fuel storage system shall also be equipped with at least one fire detector. This is also found in BV and LR’s rules but not in ABS’ rules. It is also demanded that machinery spaces must be equipped with fire detectors. Additionally, LR requires a fuel supply shutdown upon fire detection inside a machinery space. These three spaces also need fire detection arrangements according to ABS, with additional fire detectors in the ventilation trunk serving a tank connection space. BV adds that fire detection is needed in both fuel gas preparation rooms and enclosed or semi-enclosed bunkering stations. DNV GL lists fire detectors for the tank hold space, ventilation trunk for tank connection spaces and other rooms, where the probability for a fire cannot be excluded, related to the fuel gas supply system. This would mean that spaces such as tank connection spaces, fuel gas preparation rooms and possibly bunkering stations shall be fitted with fire detectors. The statement of fire detectors in spaces where fire cannot be excluded can also be found in the IGF Code, BV’s and LR’s rules. Fire detectors for ESD-protected machinery spaces are separately mentioned in the DNV GL’s rules. For neither of the spaces mentioned in DNV GL’s rules, actions upon fire detection are stated. (International Maritime Organization, 2015) (Bureau Veritas, 2017) (Lloyd's Register, 2019) (American Bureau of Shipping, 2016) (DNV GL AS, 2019)

4 Result

The purpose of this thesis was to create a document as part of our engineering manual. Having studied the IGF Code and four classification societies' interpretations of the IGF Code, five documents containing the instrumentation requirements were established. These documents are arranged for easy searching for classification society, and the requirements set by desired classification society. The documents are created as a wiki, to easily be able to click on titles containing requirements that is wanted to be seen. The classification societies and IMO are set up as separate files in a wiki and can easily be accessed by clicking on the file of society of interest. The content of the different files is every part of the fuel gas supply system and under each part of the system the classification societies' and IMO's requirements related to that part of the fuel gas supply system are listed. For every required instrument, the tag used by Wärtsilä for that specific instrument is indicated. Additionally, the chapter in which the instrument requirement was found is included. The function of the instrument, i.e. what the instrument is supposed to measure, is listed, along with the minimum actions that need to be taken as a result of reaching different values of the measured variable. The structure of the wiki is arranged much alike the structure of this thesis work. The structure of the content inside each file for every classification society is as following:

- Bunkering Station
- LNG Tank Monitoring
- Tank Connection Space
- Fuel Gas Preparation Room
- Heating Media System
- Ventilation Monitoring
- Gas Detection
- Fire Detection
- Double Walled Pipes
    - Air Ventilated

- Vacuum Insulated
- Nitrogen Pressurized

Due to the extensiveness of the thesis work, the result will be presented in appendices. The appendices are screenshots from the documents created in the wiki. These appendices are classified, which means they will be left out from the official release of this thesis work.

4.1 Analysis

Having the classification societies' requirements listed and compared to each other, significant differences between them can be noticed. Monitoring of the fuel tank does not differ much between the different societies. All classification societies and IMO require about ten different instruments to monitor process variables related to the fuel tank. Measurements inside the tank connection space, where the main process of the fuel gas supply systems takes place, the differences in requirements really stand out. There are six instruments that seem to be rather basic as they are mentioned in all set of rules. Apart from those instruments, BV, LR and IMO require only a few other instruments, meanwhile DNV GL and ABS escalate with their requirements. For these two classification societies, about ten additional instruments would be required. Fuel gas preparation rooms and heating media systems are barely mentioned in any rules except for ABS that demand around ten more instruments than the other classification societies. Bunkering stations on the other hand, are approached similarly by all classification societies, requiring roughly five instruments.

Monitoring of ventilation was one area that needed to be studied. The result shows that ventilation monitoring is almost identical for all set of rules. However, a few extra ventilation measurements are demanded by BV and DNV GL. There are some differences between the classification societies interpretations regarding ventilation, which are the ventilation capacities required for different spaces.

DNV GL has been noticed to have the broadest set of requirements for gas detection. Since the number of gas detectors are dependent of the sizes of different spaces, a good estimation of how many more gas detectors DNV GL require compared to other set of rules is hard to make. On the other hand, ABS stands out for requiring quite few gas detectors, since the 2oo2 voting philosophy is left out in their rules. Concerning fire detection, the requirements are just about the same for all set of rules. In practice it might differ to some extent, but it cannot be determined based on the rules that were studied for this work.

Some difficulties were faced when trying to find requirements for pipes arranged as double walled pipes. Lack of proper requirements for secondary enclosure monitoring for different insulation types was the biggest issue. Only a few types of insulations on only a few different pipe sections of the fuel gas supply system were found in the rules. But assumptions were made that equivalently safe solutions applies to all pipe sections of the system, requiring monitoring of all double walled pipes, even though specific requirements for certain double walled pipe arrangements are missing in the rules. The study of the double walled pipes resulted in instrumentations that barely differ between the classification societies.

5 Conclusion

The introduction needed for understanding this thesis was well accomplished. The different types of working principles the sensors are based on were well explained on manufacturers' webpages and in books. This was the best way to put together the technical aspect of background knowledge needed for this thesis. The description of the functionality and design of marine fuel gas supply systems was covered on a general level for easiest possible comprehension.

The specific requirements for fuel gas supply systems were found in Part A-1 of the IGF Code. After having the IGF Code covered and the requirements summarized in a document, the first classification society, BV, was studied. BV's rules have a similar set-up as the IGF Code. It is a copy-paste of the IGF Code, with BV's own comments and additional requirements stated directly under the affected statement of the IGF Code. The approach taken to the investigation of these rules were to gather the requirements on instrumentation and other essential equipment in a document, highlighting the differences between the IGF Code and these rules.

The second classification society that was studied was LR, that have a more up-to-date set of rules. These rules have an almost identical layout as the BV's rules, allowing for a quicker study of the rules. LR's interpretation of the IGF Code was noted in a document to get a good overview of the regulations. Following LR, a study of the ABS rules was carried out. These rules required a little bit more time-consuming study as this classification society has written its rules in their own way, not referring to the IGF Code directly. This made it more difficult to comprehend what requirements are similar to those found in the IGF Code. The last classification society to be investigated was DNV GL. These rules are written completely by DNV GL itself. The section that was studied is set up with many cross-references to other sections of the whole package of rules, making it easy to navigate to other parts of the rules referred to. The rules are however written neatly and were easy to study.

The most important parts of the classification societies' rules are the tables, where many of the requirements are found. The tables also contain what actions some of the instruments are required to take. All requirements are nonetheless not stated in the tables. The requirements can be found anywhere in the rules. That is the main reason why a lot of time was spent on fulfilling this thesis.

When writing down the required instrumentation for the fuel gas supply system, the tags for the instruments had to be the right tags that are used in the LNGPac^{TM}. This required a lot of studying of P&IDs for several different projects. As the rules might be tricky to understand, the P&IDs were helpful for seeing how some of these requirements are fulfilled in practice. An extensive internal I/O list has also been studied to get the right instrumentation tags for some of the required instruments.

The documents in the wiki that was established as a result of this study is only the very first version for any kind of gathering of classification societies' requirements for marine fuel gas supply systems. The wiki gives a good overview of what the different classification society require for the fuel gas supply system. To establish a wiki of this type, an incredibly time-consuming study of the different rules and regulations was required. This is undoubtedly the reason why a document like this has not been formed until now, seven years after the Fuel Gas Supply Systems' operations began.

As the business line is growing and a noticed increase of newcomers to all engineering teams working on delivering the LNGPac^{TM}, it was about time to get this type of input to the design work. Having this document will not only ease the introduction for newcomers, it will also help the more experienced design engineers. Time spent on searching for requirements in the rules can hereby be avoided.

5.1 Future development

Some of the rules and regulations studied for this thesis are three and four years old. New releases of ABS' and BV's regulations may be expected in the upcoming years. The other rules that were released in 2019 will also be updated at some point. As new versions are released, it is important that the document this thesis resulted in is continuously updated. It should not stop with this version, otherwise the purpose of the document will be lost.

Along with the five different files, containing every classification society's requirements, a sixth file containing a standard solution will be created. This standard solution will contain a combination of the instrumentation requirements demanded by all four classification societies. This would allow for a standard list of instruments that would result in a marine fuel gas supply system, approved by all four classification societies.

The four classification societies that have been covered in this thesis are only a few. There are numerous other classification societies out there that have classified and will classify the LNGPac^{TM}. At some point, other classification societies' requirements should also be included in the document to facilitate the future delivery projects for Fuel Gas Supply Systems.

5.2 Own reflections

I have realized that trying to learn and gather the instrumentation related requirements is not as easy as it might sound. The rules are not easy to interpret and each set of rules that were studied are over 100 pages long, which prepared me for a challenging and time-consuming study of the rules. Throughout the study of the rules, I have truly learned a lot. Furthermore, it was very instructive to study the working principles different sensors are based on.

As I already mentioned it was important to get this input to our engineering manual, and I really hope these documents will ease the process of the early design work for our projects. The classification societies' requirements have a major impact on the work we do at Fuel Gas Supply Systems, so it was very important to learn what kind of monitoring and safety actions the different societies require for the LNGPac^{TM}. Although this might not be a perfect gathering of all instrumentation related requirements set by these organizations, I am satisfied with the outcome of this thesis. It was an interesting topic for my thesis work.

6 References

American Bureau of Shipping. (n.d.). Retrieved February 10, 2020, from ABS: https://ww2.eagle.org/en/about-us.html

American Bureau of Shipping. (2016, March). Retrieved from ABS: https://ww2.eagle.org/en/rules-and-resources/rules-and-guides/archives.html

Budimir, M. (2019, February 14). Retrieved from Motion Control Tips: https://www.motioncontroltips.com/what-are-capacitive-proximity-sensors/

Bureau Veritas. (n.d.). Retrieved February 10, 2020, from Bureau Veritas: https://group.bureauveritas.com/group

Bureau Veritas. (2017, January). Retrieved from Bureau Veritas: https://marine-offshore.bureauveritas.com/nr529-gas-fuelled-ships

Cope, K. (2018, April 23). Retrieved from RealPars: https://realpars.com/plc_power_supply/

Cope, K. (2018, April 9). Retrieved from RealPars: https://realpars.com/what-is-hmi/

DNV GL. (n.d.). Retrieved February 10, 2020, from DNV GL: https://www.dnvgl.com/about/index.html

DNV GL AS. (2019, October). Retrieved from DNV GL: https://rules.dnvgl.com/ServiceDocuments/dnvgl/#!/industry/1/Maritime/1/DNV%20GL%20rules%20for%20classification:%20Ships%20(RU-SHIP)

Endress + Hauser. (n.d.). Retrieved March 14, 2020, from Endress + Hauser: https://www.endress.com/en/field-instruments-overview/flow-measurement-product-overview/Coriolis-mass-flowmeters

Endress + Hauser. (n.d.). Retrieved March 13, 2020, from Endress + Hauser: https://www.fi.endress.com/en/field-instruments-overview/pressure/Absolute-gauge-pressure-measurement

Endress + Hauser. (n.d.). Retrieved March 14, 2020, from Endress + Hauser: https://www.fi.endress.com/en/field-instruments-overview/flow-measurement-product-overview/Vortex-flowmeters

Endress + Hauser. (n.d.). Retrieved from Endress + Hauser: https://www.endress.com/en/field-instruments-overview/flow-measurement-product-overview/Electromagnetic-flowmeters

Endress + Hauser. (2018, March). Retrieved from Endress + Hauser: https://portal.endress.com/wa001/dla/5001053/9178/000/03/FA00005DEN_1816.pdf

ESI Technology Ltd. (2012, January 23). Retrieved February 16, 2020, from ESI: https://www.esi-tec.com/blog-pressure-sensors-transmitter-transducer/2012/01/what-is-the-difference-between-a-pressure-transducer-and-transmitter

Health and Safety Executive. (2004, September 22). Retrieved from HSE: https://www.hse.gov.uk/comah/sragtech/techmeasareaclas.htm

Honeywell Analytics. (2013). Retrieved March 27, 2020, from Honeywell Analytics: https://www.honeywellanalytics.com/~/media/honeywell-analytics/documents/english/11296_gas-book_v5_0413_lr_en.pdf?la=en

International Gas Union (IGU). (2019, June 7). Retrieved February 20, 2020, from IGU: https://www.igu.org/sites/default/files/node-news_item-field_file/IGU%20Annual%20Report%202019_23%20loresfinal.pdf

International Maritime Organization. (n.d.). Retrieved February 25, 2020, from IMO: http://www.imo.org/en/About/Documents/What%20it%20is%20Oct%202013_Web.pdf

International Maritime Organization. (2015, June). Retrieved from IMO: https://edocs.imo.org

International Maritime Organization. (2020). Retrieved February 18, 2020, from IMO: http://www.imo.org/en/mediacentre/hottopics/pages/sulphur-2020.aspx

Leroux, P. (2012, March). Retrieved from IECEx: https://www.iecex.com/archive/dubai/speakers/Day%202_0830-0915_IECEx_Dubai_Area_Classif_final_Leroux_P.pdf

Lloyd's Register. (n.d.). Retrieved February 10, 2020, from Lloyd's Register: https://www.lr.org/en/who-we-are/

Lloyd's Register. (2019, July). Retrieved from Lloyd's Register: https://www.lr.org/en/rulefinder/

Mokhatab, S., Mak, J. Y., Valappil, J. V., & Wood, D. A. (2014). *Handbook of Liquefied Natural Gas.* Oxford: Gulf Professional Publishing.

Peak Sensors. (n.d.). Retrieved February 13, 2020, from Peak Sensors: https://www.peaksensors.co.uk/what-is/pt1000-sensor/

Process Parameters. (n.d.). Retrieved February 14, 2020, from Process Parameters: https://www.processparameters.co.uk/pt100-sensor-working-principle/

Richardson, D. (2018, August 6). Retrieved April 3, 2020, from RealPars: https://realpars.com/plc-basics/

Sames, P. C., Clausen, N. B., & Andersen, M. L. (2011). Retrieved from MAN Diesel & Turbo: https://marine.mandieselturbo.com/docs/librariesprovider6/technical-papers/costs-and-benefits-of-lng.pdf?sfvrsn=18

Schaps, K. (2019, September 16). Retrieved February 20, 2020, from Petroleum Economist: https://www.petroleum-economist.com/articles/midstream-downstream/lng/2019/lng-fuelled-ship-order-book-bulges

Shawn. (2019, December 19). Retrieved from Seeed: https://www.seeedstudio.com/blog/2019/12/19/all-about-proximity-sensors-which-type-to-use/

Thomas. (n.d.). Retrieved March 13, 2020, from Thomas: https://www.thomasnet.com/articles/instruments-controls/pressure-sensors/

Toscano, N. (2020, January 6). Retrieved February 20, 2020, from The Sydney Morning Herald: https://www.smh.com.au/business/the-economy/australia-tops-qatar-as-world-s-biggest-lng-exporter-20200106-p53p5h.html

Waldemar, N. (2005). *Measurement Systems and Sensors.* Artech House.

Walton, J. (2017, January 3). Retrieved from Bronkhorst: https://www.bronkhorst.com/int/blog/the-importance-of-mass-flow-measurement-and-the-relevance-of-coriolis-technology-en/

Wilson, J. S. (2004). *Sensor Technology Handbook.* Elsevier Science & Technology.

Wärtsilä. (n.d.). Retrieved April 2, 2020, from Wärtsilä: https://www.wartsila.com/marine/build/gas-solutions/fuel-gas-supply-system/lngpac

Wärtsilä. (n.d.). Retrieved March 18, 2020, from Wärtsilä Encyclopedia of Marine Technology: https://www.wartsila.com/encyclopedia/term/classification-societies

Wärtsilä. (n.d.). Retrieved February 19, 2020, from Wärtsilä Encyclopedia of Marine Technology: https://www.wartsila.com/encyclopedia/term/cargo-tank-of-gas-carrier