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IMPROVEMENT OF RECIPROCATING ENGINE POWER PLANTS COMPETITIVENESS AND MITIGATION OF TECHNOLOGY RISK BETWEEN GAS TURBINE POWER PLANTS BY MEANS OF PRODUCT SAFETY.

Opinnäytetyö
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TIIVISTELMÄ OPINNÄYTETYÖSTÄ

Yksikkö Kokkola	**Aika** Toukokuu 2017	**Tekijä** Ville Manninen
Koulutusohjelma Teknologiaosaamisen johtamisen koulutusohjelma		
Työn nimi MÄNTÄMOOTTORIVOIMALAITOSTEN KILPAILUKYVYN PARANTAMINEN JA TEKNOLOGIARISKIN PIENENTÄMINEN KAASUTURBIINIEN VÄLILLÄ TUOTETURVALLISUUDEN KEINOIN.		
Työn ohjaaja Marko Forsell		**Sivumäärä** 79+5
Työelämäohjaaja Niklas Wägar, Sari Kojo		

Työssä tutkittiin, kuinka mäntämoottorivoimalaitosten kilpailukykyä voidaan parantaa kaasuturbiinien hallitsemalla markkina-alueella Yhdysvalloissa tuoteturvallisuuden keinoin. Lisäksi tavoitteena oli pienentää asiakkaiden mieltämää teknologiariskiä mäntämoottorivoimalaitoksia kohtaan. Työ tehtiin Wärtsilälle ja rajattiin Wärtsilän Smart Power Generation –voimalatioksiin, joiden pääasiallisia kilpailijoita ovat kaasuturbiini valmistajat.

Teoriaosuudessa tutustuttiin kaasuturbiini- ja mäntämoottorivoimalaitosten teknologiaan. Lisäksi käytiin läpi näiden historiassa tapahtuneita onnettomuuksia, tutkittavan markkina-alueen ominaisuuksia, vallitseva lainsäädäntö ja standardeja tuoteturvallisuuden puolella sekä yleisesti kilpailukykyyn liittyvää teoriaa.

Tutkimus toteutettiin kyselytutkimuksena, johon kohdehenkilöiksi valittiin henkilöitä organisaation eri osa-alueilta. Yhteistä kohdehenkilöille oli, että he ovat työskennelleet alalla pitkään ja olleet läheisessä yhteistyössä asiakkaiden kanssa. Myös kokemus molemmista teknologioista on ollut toivottavaa henkilöitä valittaessa.

Tutkimustulos osoitti, että sisäisiä toimintatapoja muuttamalla ja eri elinkaaren vaiheisiin, kuten markkinointiin ja myyntiin, tietotaitoa lisäämällä voidaan lisätä kilpailukykyä ja osittain pienetää teknologiariskiä. Osittainen teknologiariskin pienentäminen johtuu siitä, että tutkimustuloksien perusteella teknologiariski on myös muuta kuin tuoteturvallisuuteen liittyviä asioita, joita ei voida perustella turvallisuuden hallinnalla.

Sivumäärä: 79+5

Asiasanat
Kilpailukyky, Energia, Kaasuturbiini, HSE, Voimalaitos, Tuotevastuu, Tuoteturvallisuus, Mäntämoottori, Riskienhallinta, Turvallisuus, Smart Power Generation, Teknologia riski

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Instructor Marko Forsell		**Pages** 79+5
Supervisor Niklas Wägar, Sari Kojo		

The aim of the study was to investigate how competitiveness could be improved in gas turbine driven markets in United States, and to mitigate customer seen technology risk for reciprocating engine power plants by means of product safety. Main market area in this research was United States. Research scope was limited to Wärtsilä Smart Power Generation -power plants, which main competitors are gas turbine companies.

Theoretical part of the thesis examines background of both technologies. This includes gas turbines and reciprocating engine technologies, and their accidents back in history, exploration of United States market, local legislation and guiding standards from product safety as well as general information related to competitiveness.

The research was done by survey and by interviewing selected persons from different areas of the organisation. Selected persons have been working long time in the industry and have been in close operation with customers. Also, selected persons should have had experience both from gas turbines and reciprocating engine power plants.

Results showed that with changing internal communication and way of working, and adding competence of product safety awareness in areas like sales and marketing, competitiveness can be increased and the technology risk can be decreased. Based on the results, technology risk is more than just product safety, and for that reason cannot be fully mitigated.

Pages: 79+5

Key words
Competitiveness, Energy, Gas turbine, HSE, Power plant, Product liability, Product safety, Reciprocating engine, Risk management, Safety, Smart Power Generation, Technology risk

ABBREVATIONS

ALARP	As Low As Reasonable Practical
ANSI	American National Standard Institute
ASME	American Society of Mechanical Engineers
BSC	Balance Score Card
CAISO	California Independent System Operator
CCGT	Combined Cycle Gas Turbine
CFR	Cleaning Force Ratio
CGR	Compact Gas Ramp
CHP	Combined Heat and Power
DC	Direct Current
DIN	Deutsches Institut für Normung
EEQ	Engineering
EPC	Engineering, Procurement, Construction
F(E)RA	Fire (and explosion) Risk Assessment
FERC	Federal Energy Regulatory Commission
FTA	Fault Tree Analysis
GT	Gas Turbine
HAZID	Hazard identification
HAZOP	Hazard and operability study
HSSE	Health Safety Security Environment
HSSE	Health, Safety, Security Environment
HV	High Voltage
IPP	Independent Power Producer
IRENA	International Energy Agency
ISO	Independent System Operator
ISO	International Standardisation Organisation
KPI	Key Performance Indicator
LEL	Lower Explosion Limit
LNG	Liquefied Natural Gas
LOPA	Layer of Protection Analysis
LV	Low voltage

MISO	Minnesota Independent System Operator
MV	Medium Voltage
NFPA	National Fire Protection Agency
NFPA	National Fire Protection Association
NOx	Nitrogen Oxides
OHSAS	Occupational Health and Safety Association
PFD	Probability of failure on demand
PFH_d	Probability of dangerous failure per hour
QRA	Quantitative Risk Assessment
RCA	Root Cause Analysis
RTO	Regional Transmission Organization
SCR	Selective Catalytic Reduction
SIF	Safety Instrumented Function
SIL	Safety Integrity Level
SIS	Safety Instrumented System
SPG	Smart Power Generation
TSO	Transmission System Operator

TIIVISTELMÄ

ABSTRACT

ABBREVIATIONS

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1 INTRODUCTION

This research aims to find ways how to change the industry mind-set in the USA, with the help of product safety aspects used in sales and marketing, from Combined Cycle Gas Turbine (CCGT) power plants to reciprocating engine power plants. Research question for this research was about what is needed to be highlighted from reciprocating engine power plants, and further, to be developed from customer point of view to raise product safety and reduce concern of technology risk.

Scope is limited for Wärtsilä Smart Power Generation (SPG) power plants and the selected market area is United States of America (U.S.). The market area was selected because the customers have used CCGT back in history and perceive technology risk in reciprocating engines compared to CCGT. Due this CCGT is current dominating technology, and mind-set change would be needed to prove the reciprocating power plant capabilities.

For U.S. customers as well as many others, reciprocating engine power plants are unfamiliar from the technology and their capabilities. Customers are unaware and not confident about new and different technology they have not used to have. For example the SPG has meaning capability to follow daily electricity by starting and stopping the engines, and operating them with high efficiency based on electricity, when CCGT´s are not capable to follow the electricity demand with the same efficiency. High number of components in reciprocating engine power plants can be seen as a mark of unreliability. The difference is from twenty engines with supporting auxiliaries in reciprocating engine driven power plant to couple of CCGT.

Available literature and reports, both internal and external have been used for material acquisition as basic information to form background. Internal stakeholders have been interviewed and results are collected to experimental part with the few supporting business cases. 30 persons from different positions were selected based on their experience with the selected market environment, both technologies and experience with customers.

Experiences from U.S. market area has been collected by having discussions around the different organisations and divisions to compare other companies' activities in the market during course of history. The aim of this research is to clarify the differences regarding product safety in CCGT and reciprocating engine power plants. In general CCGT are running with higher rounds per minute (RPM’s), which set higher demand on strength of the structure and guarding.

The research question was selected because it is ongoing matter in many ways. One is that requirements from product safety are going to be more stringent and secondly the market situation is tough in energy business. Product safety matters are especially raised within safety oriented customers and demanding energy applications.

Following matters have been identified as bottle necks for this research. Main concern was that the market area is extensive by all means. This may have impact for the reason that there are lot of matters which are connected to each other and deeper investigation might be needed. Also, information from the research what can be received from the product safety can be limited.

The third chapter of the thesis gives basic information regarding competitiveness and basic elements affecting it as well as improvement suggestions, mainly from the marketing and management point of view. The current U.S energy market state is also evaluated, especially regarding Wärtsilä´s position, what are the important things in the U.S markets from the safety point-of-view and how competitors are raising awareness of product safety to the customers.

In the fourth chapter, product safety in general level is described concerning similarities in both power plant types. It describes the occupational health and safety, product safety, and the past accidents in the history of turbines and reciprocating engines. The chapter is concluded with standards and legislations, including comparison between these two technologies and does the legislation reflect the occurred accidents.

In the next two main chapters the focus is on the turbine and reciprocating engine power plants design and technology, including systems’ main equipments and risks in these plants. In the latter chapters the experimental part is described including the methods used and results of the material acquisition. Results will consist of comparison of the two plant types interview results, and the business cases.

Finally, there is improvement suggestions and the conclusion of this work.

2 IMPROVEMENT OF COMPETITIVENESS

This chapter examines overall competitiveness improvement and matters that are affecting on the company effectiveness. Marketing of the key values to specific customers is one of the key items for effective sales. This requires solid understanding of market environment and customers, as well as persons with adequate competences to bring strengths of company visible for the customer.

There are several things that are important when developing company and its organisations. These are continuous learning, building the competence, multi-formity, and co-operation between persons and companies. Without these the company will stay in its comfort zone and it is not challenging anymore either itself or competitors. Finally, competitors will take available markets. Most important thing is the challenging customers, which are the ones making the change. (Alahuhta 2016, 128-133.)

2.1 Marketing

Marketing of products and solutions is an important factor in current situation as the competition is tough and overall market situation in general has been weak for years due different worldwide financial crisis. While the used technology has come available for all, company image and product marketing is more important than it has been earlier. High technology has become available for all, and it is easier to develop high class technology innovations for customer needs than it has been in the past. The market and the customer need to be understood, as well as the market environment so that their needs can be met. Regarding this, the marketing activity should be cross-disciplinary to present needed value to the customer of the offered solutions. (Davidow 1989, 9-12; Hooley, Saunders & Piercy, 2004. 8-11, 28-35.)

It is important to understand what the customer segment is and what an environment is where the products are targeted. Customer needs need to be understood, and based on that you need bring up relevant matters from the offered solutions and company principles to provide value for. If the customer is in the Oil & Gas segment, they are very safety oriented. This requires from company´s representative ability to discuss the means to reach the required product safety level with the representative and convincing. It is required to show, how you could perform better than competitors in all areas of company. It is important that the sales, marketing or whoever influencing representatives are aware and capable to discuss with the correct matters. Customer should always be the top priority, as an unsatisfied customers will not buy again. (Davidow 1989, 18-20; Hooley, Saunders & Piercy 2004, 8-11, 23.)

Another important matter is to be visible around the customers. Participation to seminars and presenting your company, and especially the benefits of your products will raise the interest of customers. Effort that is put for this kind of visible work shows already the passion and quality of company to customers. (Davidow, 20-24). There are only few worldwide seminars in few locations annually where power plant customers from Oil & Gas segment are gathered around to discuss product safety. These seminars are places to lobby safety in power plants and the company way-of-working. Example of such seminars are provided by associations like ICheme (The Institution of Chemical Engineers), DeChema (Gesellschaft für Chemische Technik und Biotechnologie e.V. (Society for Chemical Engineering and Biotechnology)) and AIChE (American Institution of Chemical Engineering). It is interesting that other companies delivering power plants are not participating to these seminars, neither as participants nor as presenters in order to promote their products or to learn to understand the customers' priority in safety.

Customers' decision to invest lot of money for years to high technology is affected by many things. In the power plant industry, main questions are related to supplier's reliability and availability of power plant, maintenance costs, and suppliers' problem solving in case of malfunction, capital expenditure (CAPEX) and power plant capabilities to respond electricity demands. Markets are generally consisting of different customers, sub-markets and segments, which have different matters that customers prefer. They may invest for variety of reasons, which in energy industry can be the quality and experience, safety and environmental, performance and value brought by the solutions to respond electricity needs, or any other combination of these. (Hooley, Saunders & Piercy 2004, 24.)

Market segment can have several features which affect to the customers decision regarding preferred power plant provider. The Oil & Gas segment have different interests compared to local energy company regarding the planned power plant. For the specific segment, it is needed to have capable marketing and sales persons to sell high technology products, and understand the value that can be offered to the specific customer. While discussing with safety oriented customer, it is important to have common language to communicate in order to convince customer. (Davidow 1989, 32-42, 59.) Positively, it is not necessary to have the best product as itself, and it may be that it would not even be enough to have such. The customer choice is more based on the overall package. When overall effect of provided solution is superior to other options, then some minor defects can be accepted. (Davidow 1989, 51.)

2.2 Management importance and resources

It is extremely important that the top management is committed to the company´s strategic goals. The focus on goal needs to be preserved through the organisation. Company employees are not committed to perform tasks or serve customers in a way they could, if the top management is not capable to show an example. This relates for the identification of the markets where the company is led, and how well the competence is known and managed to the new business. There are examples of companies that have entered to the new business areas having thoughts of really promising market forecasts, but where they actually had no basis to compete. (Hooley, Saunders & Piercy 2004, 9-17, 22-23.) Management and superiors should be strict, clear on their visions, demanding but still give responsibilities for the employee, and listen them to help them to develop further, which especially is important to junior experts. Listening of employees is equally important as listening the customer needs. (Alahuhta 2016, 128-133.)

Different competiveness and market analysis tools used for market environment mapping should include the product safety and legislation related to it in a more detailed level to analyse its requirements for future actions. It is needed both from organisations resource point of view and to differentiate product offering in the market to understand business requirements in general level. (Hooley, Saunders & Piercy 2004, 117-119.) Legislative and other similar guidances can have a negative impact in different forms for the company business development if certain requirements have not been considered.

As it is said by Davidow (1989), the overall service and all related activities with customers requires top management commitment to success. Similar case is with all matters and especially with safety in general. In Oil and Gas industry, the companies are putting a lot effort for safety, and it all starts from the top management. Many of the companies have different rewarding and bonus systems, which are dependent on safety performance. If the management does not put effort for overall safety, in some time people in lower levels of organisations will cut level of safety because of costs, time delay or some other reason, and freezes development work in different areas of safety. This concerns also the employees and management respect towards customers. Customer will get the best available product after everyone in the company is committed to serve. If the management commitment is missing from safety or any else, it will never be one of the top priorities for the company. (Davidow 1989, 80.)

Company building a competitive positioning, should recognize existing, potential and needed recourses. Without this, it is possible that we miss potential to create a unique differentiation in customers' eyes between competitors. Resources providing the most advantage in competition should be resistant to customer imitation or duplication. Skills and networks built towards customers and other experts are difficult to copy by competitor organisation and can create difficulties for them to replicate a successful strategy.

2.3 Differentiation

According to Porter (1980) there are three different competitive strategies which are overall cost leadership, differentiation and focus. Pricing of the product and cost leadership in general can be done in various ways to improve competitiveness. Allthough this will require a big market share and working networks in various levels to achieve cost benefit that can be transacted to the product price. Differentiation is more feasible to concentrate for different customer segments or markets making the product somehow different and more attractive from the competitor products and the margins of the product can be kept higher compared to the pricing strategy. Finally we have the last strategy which has the focus in some certain customer segment, buyer group or certain part of the world, et cetera. Target of this strategy is to serve customer as best as possible to same time justify higher margins and continual purchasing. (Porter 1980, 34-39.)

2.4 Balanced scorecard and key performance indicators

Balanced scorecard (BSC) is developed by Robert Kaplan and David Norton in the beginning of 1990. BSC was part of a research where target was to improve measuring of the company performance. Reason behind this development was that companies used to follow only financial statistics, which gave too narrow view point for overall picture. Prior the BSC, essential matters for success like personnel and customer satisfaction, and development of internal procedures were left for too little attention. Method developed by Kaplan and Norton combined these financial and functional matters as one, which is now used as a tool for strategic leadership. (Vuorinen 2013, 53-58; Kaplan & Norton 1992, 123-128.)

The idea of the BSC is to transform a strategic state in to an operative state with indicators and functional plans. Basis for this tool is that the strategy of the company is divided for strategic targets, critical success factors, and key performance indicators which describe the success factors best, and for functional plan which is used to get to the target set by the indicators. Example of the structure is shown in Figure 1. (Vuorinen 2013, 53-58; Kaplan & Norton 1992, 123-128.)

Usually the overall target is to have excellent financial numbers for the company as a result, and usually this is done by having satisfied customer. In order to reach having a satisfied customer, the company needs to have all 4 areas of balanced scorecard in order. (Vuorinen 2013, 53-58; Kaplan & Norton 1992, 123-128.)

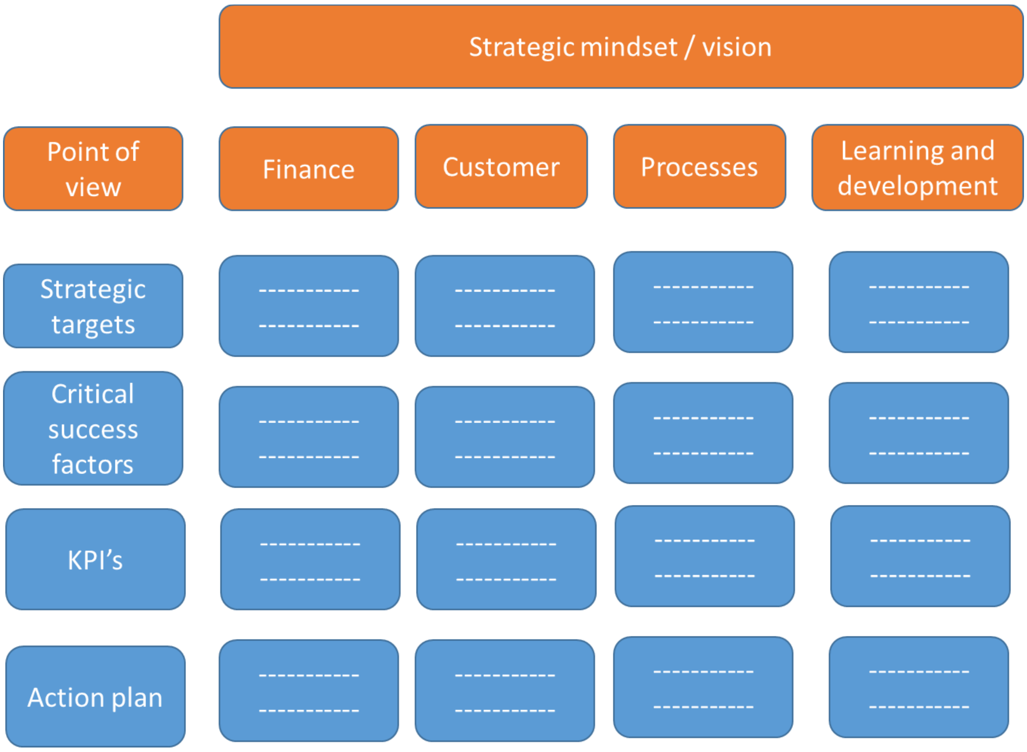

FIGURE 1. Balanced scorecard frame (Vuorinen 2013, 53)

For all what needs to be controlled should be set some indicators in order to measure and control the function. An example of this related to power plant industry would be following. If the strategy is to enter in Oil & Gas business or similar where the product safety is one of the matters customers are heavily keen on, one of the KPI's should measure this feature to be able to give feedback how the strategic target can be reached.

2.5 Energy markets in the United States of America

Energy markets in the U.S. are enormous compared anywhere else in the world. Renewables energy proportion is big and getting bigger in the future because of the climate change challenges. Currently U.S. produces more geothermal energy than any other country (2,640MW), more biomass power than any other country (15,407MW), is the second largest producer in wind energy sector (73,751MW), third largest in hydropower sector (79,298MW) and the fourth biggest in solar power sector (27,810MW). Target is that the renewables sector would be 27% of the total amount of produced energy by the 2030 along with the International Renewable Energy Agency (IRENA). Also, well the renewable fuels have increased their capacity. Renewable fuels include both ethanol and pellet. (Select USA 2016)

U.S. is currently the leader in the natural gas production, and major origin for oil and gas research and development. U.S. has enhanced their market position by developing different technologically advanced methods to extract hydrocarbons from shale, and hard-to-reach offshore oil and gas deposits. Coal is still major energy source in the U.S., and currently 33% of electricity is produced with coal, when 20% of electricity is produced by nuclear energy. Allowing U.S. producers to ship crude oil and liquefied natural gas (LNG), has made the U.S. market even more ambitious. (Select USA 2016)

Currently, the summer load forecast for 2016 was quite limited to the past having almost any changes. Total generating capacity in the U.S. is decreasing with small portions, which is because of old coal based power plants. Factors that are affecting for reduced coal power plants are the competitive natural gas, different environmental legislative regulations and average age of more than 50 years. (Federal Energy Regulatory Commission, summer 2016, Energy Market and Reliability Assessment,). In the report where are forecasts for winter 2016-2017, is mentioned that the power generation is shifting away from large centralized power plants towards to smaller distributed power plants. These would be small to mid-size generators being less than 400MW, and renewable projects. These generators would take 90 % market share from this expected coming power generation and renewables almost 80 % of new generating capacity over time frame. Small amount of nuclear power plants is also expected to retire in the future. (FERC 2016. Energy Market Assessment). To enable all this new distributed power generation, allowing network for increased capability and reliability to transmit energy for end users, transmission lines need also upgrading for future demands.

U.S. is the global leader in the research and development, and deployment of smart grid technologies and services. Increase of investments may be expected in the future because of reliability enhancement, connecting to renewables, demand shifts, costs increases and market improvement. (Select USA 2016)

A Regional Transmission Organization (RTO) in the U.S. is an electric power Transmission System Operator (TSO) which coordinates, controls and monitors a multi-state electric grid. The transmission of electricity among states is considered interstate business and electric grids connecting multiple states are therefore regulated by the Federal Energy Regulatory Commission (FERC). Establishment of independent RTO's was initiated by FERC in 1999 and purpose of this is to develop economic efficiency, reliability and non-discriminatory rules while reducing government surveillance. (FERC 1999. Regional Transmission Organizations, 1-29.)

Similarly, independent System Operator (ISO) is an organization formed at the recommendation of the FERC. In the areas where ISO is settled, it regulates, manages and monitors the operation of the electric power system, usually within a single U.S. state, but sometimes surrounding multiple states. RTOs typically perform the same functions as ISOs, but cover a larger geographic area. (FERC 1999. Regional Transmission Organizations, 1-29.)

In short terms, an ISO operates a region's electricity grid, govern the region's wholesale electricity markets, and administers reliability planning for the regions mass electricity system. RTOs perform similarly but with greater responsibility for the transmission network. (FERC 1999. Regional Transmission Organizations, 1-29.)

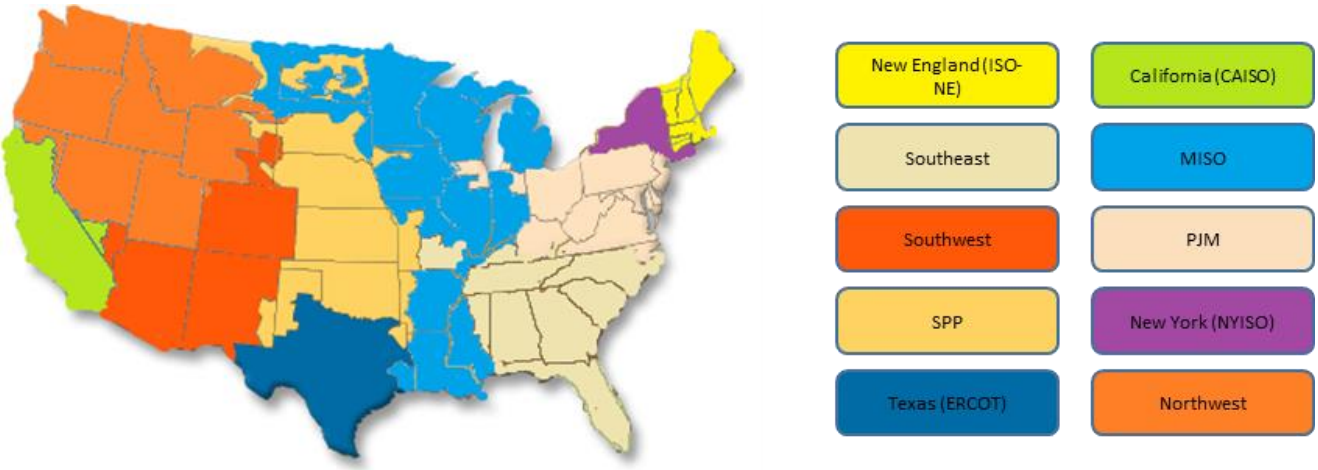

FIGURE 2. Overview of U.S. Electric Power Markets, national view (FERC. National overview.)

In the Figure 2 is presented the overview of the U.S. electric power markets. There can be seen that the wholesale electricity markets are regionally divided and these transmission systems are operated by specific ISOs. (FERC. National Overview.)

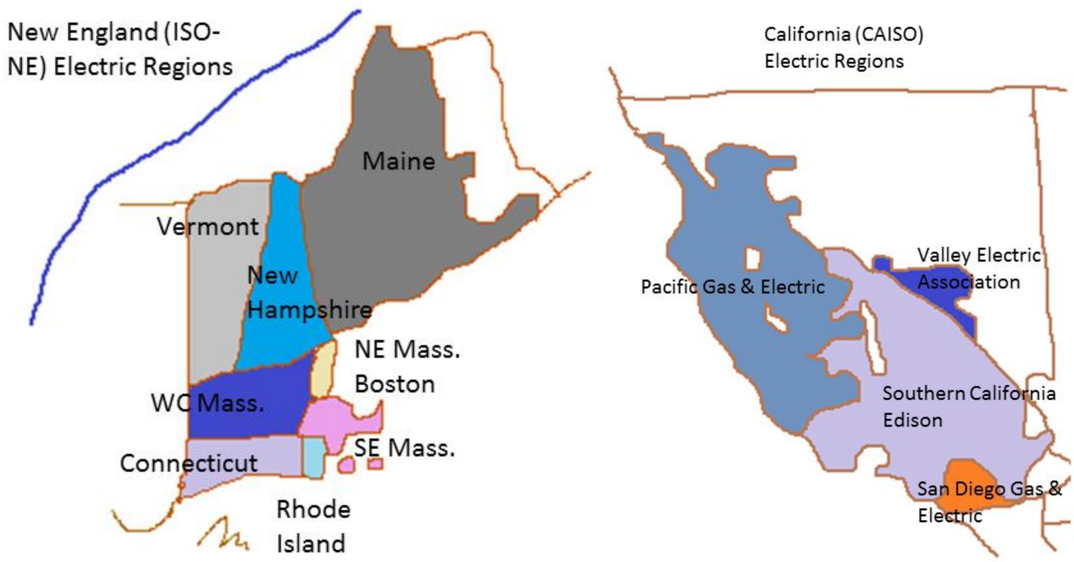

FIGURE 3. Example of U.S. Electric Region, the New England (ISO-NE) and the California Independent System Operator (CAISO)

In the Figure 3 is presented couple of examples from electric regions, New England on the right side and California Independent System Operator (CAISO) on the left side. (Federal Energy Regulatory Commission, Electric Power Markets – California and Federal Energy Regulatory Commission, Electric Power Markets: New England (ISO-NE))

2.5.1 Wärtsilä market position in the United States of America

Wärtsilä is the global leader of reciprocating engine manufacturers in power plant segment. Power plant business in Wärtsilä is within the Energy Solution business line. Biggest competitors in the power plant markets having gas turbine technology are the General Electric (GE) and Siemens, which have big market share of the large size power plants. Third one is Mitsubishi, and Wärtsilä comes then with rest of the manufacturers as described in Figure 4. Figure 5 represents market positions of the reciprocating engine manufacturers where Wärtsilä has the leading position.

One of the advantages in the reciprocating engine markets is the capability to respond quickly to the load variation caused by renewables. Renewables in that sense increased demand for grid stability which was also one of the criteria beside the emissions in STEC red gate. It is mentioned in the report that larger baseload units (e.g. gas turbines, coal power plants and so on) are unable to respond quickly enough and with certain reliability to the large swings in generation caused by connection of large quantities of renewables to the grid. Related to the operation of the plant, estimate has been that there would be 730 start ups and shutdowns while the frequency of the operation is unknown. (US EPA. 2014, 5-6, 9-10.)

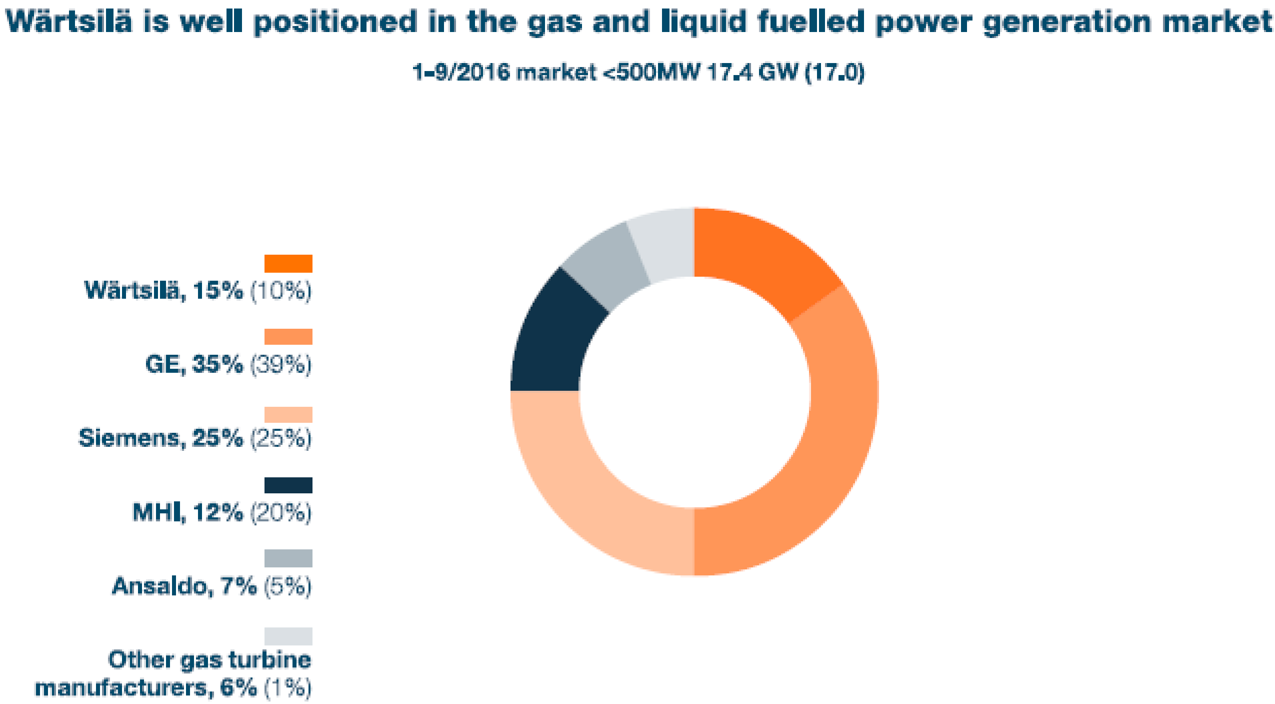

FIGURE 4. Market share, Total market (Wärtsilä 2016. Annual report. 30-31)

Market data presented in Figure 4 includes all Wärtsilä power plants and other manufacturers' gas and liquid fueled gas turbine based power plants with prime movers above 5 MW, as well as estimated output of steam turbines for combined cycles. Other combustion engine manufacturers are not included for this graph since Wärtsilä has leading position in the engine technology. (Wärtsilä 2016. Annual report, 30-31)

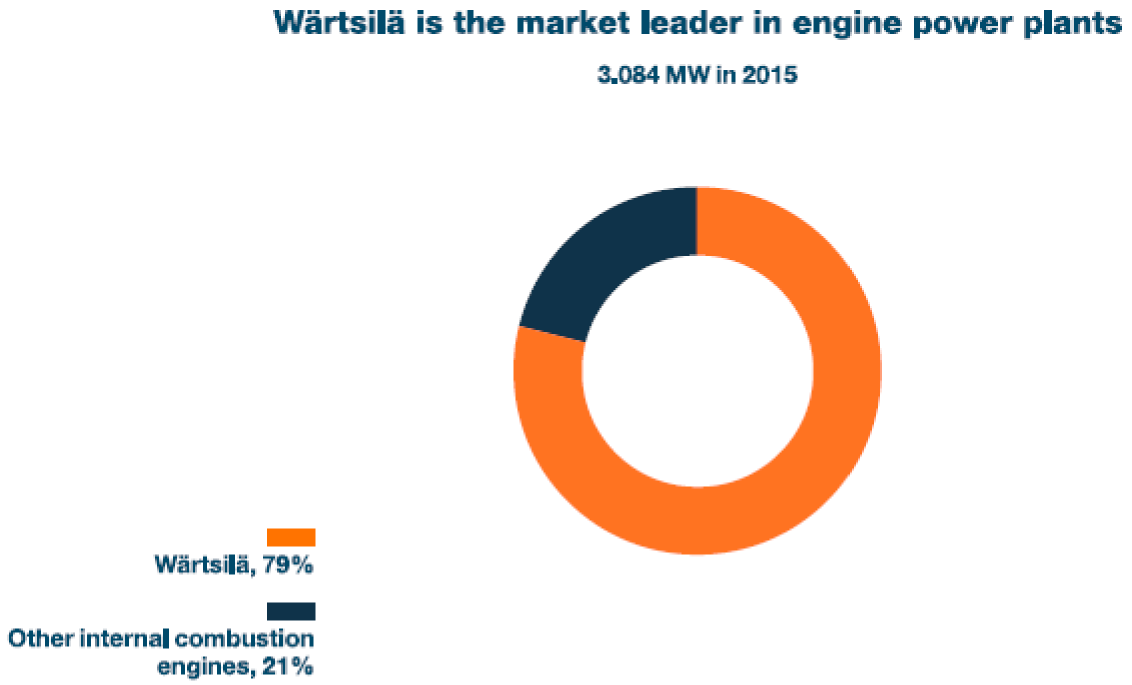

FIGURE 5. Market share, <500MW market. (Wärtsilä 2016. Annual report, 30-31)

Other Wärtsilä business lines within Wärtsilä Corporate are Marine Solutions and Service, which are as well in strong position globally. Although these are not discussed more within this research.

2.5.2 Products in liability law in the United States of America

Laws in the United States bases on the Constitution of United States which acts as foundation of the federal government. In Figure 6, this is described as a simplified process.

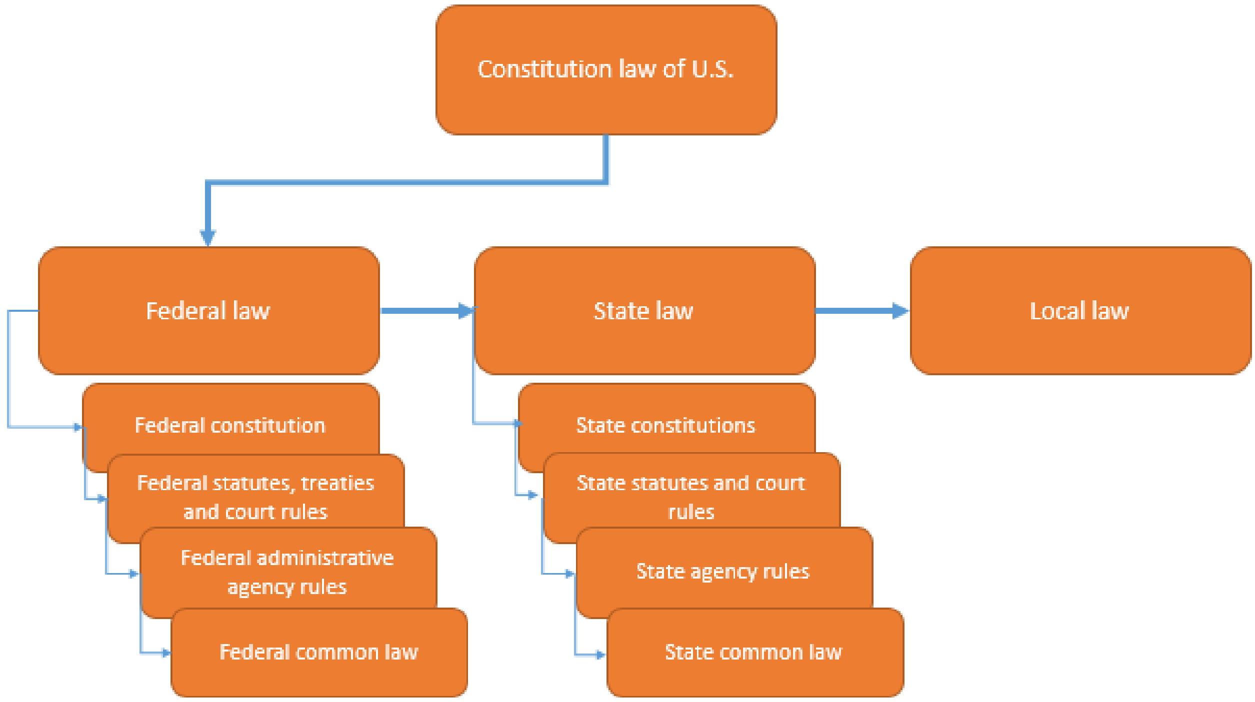

FIGURE 6. Law structuring of the U.S (Burnham W. 2016. Introduction to the Law and Legal Systems of the United States. 4)

Constitution law of United States defines the top level of law and it is the base for all of the rest. Federal law defines the boundaries for states laws which simultaneously prevents the different states to collide with each other laws. (Burnham W. 2016 Introduction to the Law and Legal Systems of the United States, 4). Product liability law is defined basically in two different forces by Courts and federal and State legislature and governmental agencies. Court defines the common law and the other one the legislative law. (King L, Prince J.D., Ross K. 2009. Product liability in Asia Pacific, 1)

Standardisation organisations such as American National Standardisation Institution (ANSI), are overviewing the development work and adoption of international standards in the U.S. These organisations have their own process, commonly open for willing participants to participate for development work, to maintain openness, balance and consensus with variety of bodies using standards. ANSI is an organisation which closely follows the development work of International Electrotechnical Committee (IEC) and International Standardisation Organisation (ISO). This works also in opposite way, meaning that the proposed standards of U.S are taken forward to IEC and ISO and adopted either as whole or partly to the international standard. Driving force in the standard development is the participants from contributing industry individuals. (ANSI 2017). This has been opened in Figure 7.

Product liability is the area of law, which concerns all parties in the product lifecycle who put products available to market and are in responsible for the possible injuries the products can cause. The parties are such like manufacturers, distributors, suppliers, retailers and similar. In the United States, product liability is claimed concerning commonly negligence, strict liability, breach of warranty and different user protection claims. Main questions in the product liability law in case of person get injured are whether the product was too dangerous according to some standard of product safety and has the product provider complied with duty to warn requirements. (American Law Institute 1998, 7.)

Different categories which are listed as product defect according to the *§ 2 of American* law institute are referred below. Special attention should be put on the warning defects where the risk level determines how it should be informed to the user. For example, is it best to inform in the instructions, or next to the occurring hazard. There are two major principles of products liability law in America, which are manufacturer's responsibility to guard against foreseeable risks and guard against those risks only with precautions which are reasonable. (American Law Institute 1998, 37, 39.)

> "A product is defective when, at the time of sale or distribution, it contains a manufacturing defect, is defective in design, or is defective because of inadequate instructions or warnings. A product:
>
> (a) Contains a manufacturing defect when the product departs from its intended design even though all possible care was exercised in the preparation and marketing of the product;
>
> (b) is defective in design when the foreseeable risks of harm posed by the product could have been reduced or avoided by the adoption of a reasonable alternative design by the seller or other distributor, or a predecessor in the commercial chain of distribution, and the omission of the alternative design renders the product not reasonably safe;
>
> (c) is defective because of inadequate instructions or warnings when the foreseeable risks of harm posed by the product could have been reduced or avoided by the provision of reasonable instructions or warnings by the seller or other distributor, or a predecessor in the commercial chain of distribution, and the omission of the instructions or warnings renders the product not reasonably safe."

Related to product defect, liability and adequate risk reduction in terms of product safety and design work, it is also important to notice following section in the American law institute;

> "§ 4 Noncompliance and Compliance with Product Safety Statutes or Regulations In connection with liability for defective design or inadequate instructions or warnings: (a) a product's noncompliance with an applicable product safety statute or administrative regulation renders the product defective with respect to the risks sought to be reduced by the

> statute or regulation; and (b) a product's compliance with an applicable product safety statute or administrative regulation is properly considered in determining whether the product is defective with respect to the risks sought to be reduced by the statute or regulation, but such compliance does not preclude as a matter of law a finding of product defect.”

There are couple of examples which are straight related to the design and risk management itself, and are important from overall safety point of view. It is not worth to list all the sections from the referred law, but there are numerous similar different sections related also to seller and distributor. Great attention should be put in the importance to warn user (duty to warn). It is mentioned in most of the points, that most important thing is to inform user of any possible harm and hidden dangers that can be caused by the product. It has even higher importance if the warning could have been the adequate risk mitigation measure for the danger. Negligence in different matters can happen in variety of points of product lifecycle, for example in design, manufacturing, installation and, commission, and it is the most common claim in the U.S. Processes and responsibilities should be clearly defined to avoid possible situations where the person could neglect something. (American Law Institute 1998, 30, 59-62)

It shall be noted that the product liability law in the U.S. is state and city specific. A lot effort for this specific part of law is that the injuries caused from the products are causing enormous costs for the nation each year. Major part of the injuries are occurred because of improper use of product by user or third party that would be otherwise safe to use. These are normally out of product liability law but there are large portion of product –related risks that manufacturer should have reasonable mitigated, and this is the part product liability law is concentrating. (American Law Institute 1998, 24-30)

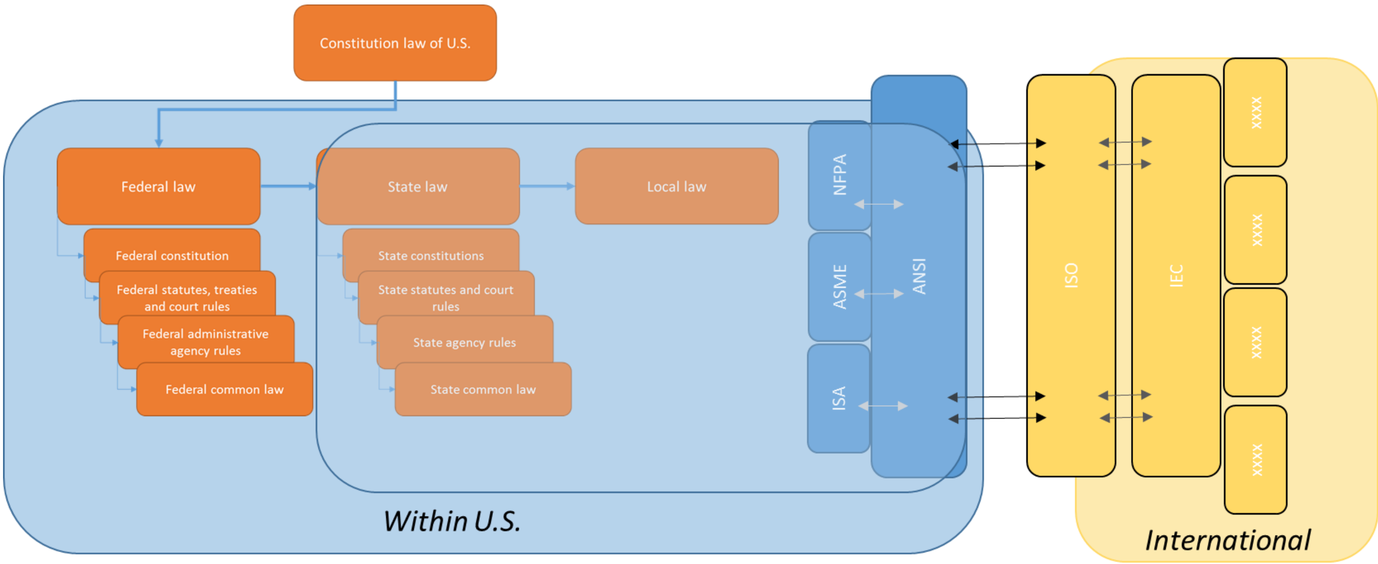

FIGURE 7. Standardisation organisations and their communication towards states and international standardisation organisations.

Figure 7. presents different standardisation organisations within the U.S. and how they are connected to each other. Not all possible standardisation organisations were collected, but only relevant examples concerning this research. Inner blue box describes that the states has the right to determine what you must comply with to fulfil product liability requirement for example. Different standardisation organisations provide the standards for use (ANSI. Resources). Following these required standards specified in some requirement, acts as justification to meet that part of compliance. ANSI is the standardisation organisation which is the most common organisation to communicate between the international standardisation organisation ISO and IEC to take standard suggestions for international use and vice versa.

2.5.3 Market argumentation and lobbying

Companies which were included for the market review were Wärtsilä, GE, Rolls-Royce, MAN Diesel & Turbo, Ahlstrom, Caterpillar and Siemens. Review concentrates on the way how these different companies show the capabilities of way of working in different areas of safety.

Gas turbine manufacturers are presenting different kind of product safety related matters through design and applications. One of these is the safety integrity level (SIL) of the protective functions and involved equipment such as control system, which is common marketing argument from both technology providers. There exists also wide range of design handbooks and investigations of hazardous scenarios for public, which have also been used in this research.

There is not much of organisational information available from the companies if is not taking into account the general words presented from the importance of safety. Most of the information is available from the companies who are involved to the nuclear, aviation or similar industries. In some extent, the safety culture can be seen in the LinkedIn of how large quantity of safety personnel is available in the company and how they are spread in the organisation. Also in Linkedin, the aviation industry in turbine manufacturers has the largest product safety and reliability professional network. Some companies do not allow to log in to see further details or project experiences without intention to buy products. From MAN, there was example presenting the simplified gate model with project activities including risk assessments in different lifecycle phases to ensure safe final product. (Laursen R. 2015)

These give impression that the product safety is one of the core values in companies, and can be seen that the company is at least in some level complying with the requirements where separate safety organisation is needed. Personnel who could be found from LinkedIn are concentrated in various tasks in different areas of product safety. Usually, if the company has high commitment for safety culture, safety is in every person’s backbone and part of their daily basis. Safety comes along the processes automatically and separate organisational safety control is not essential.

Since there is not much of marketing of reciprocating engine power plants from safety perspective, it could be used as marketing value to lob safe and environmental friendly solutions which are considering the surrounding environment and inhabitants by different safety analysis. For example, MAN power plants is not promoting safety at all, except for LNG and marine solutions, but even in these only HAZID and general risk assessment are mentioned, but not very extensive level when considering the industry practise. (Rolls-Royce, Nuclear Instrumentation & Control brochure; Rolls-Royce, Reactor protection system brochure; Rolls-Royce, Spinline - modular I&C digital platform for nuclear industry brochure; Rolls-Royce, Product safety; VDMA 4315-6 2014.)

Some U.S. based engineering companies are representing reciprocating engine technology in their material, where also Wärtsilä is mentioned in many of the references with the plant technology information. There are also benchmarking of the technology listing benefits that can be achieved with the reciprocating engines. (Burns & McDonnel, Sargent & Lundy.)

3 SAFETY IN POWER PLANTS

In this chapter is described in general level what all is included for safety of power plants. First is told about the health, safety, security and environment (HSSE), and further on concentrating on actual product safety. Cyber security is briefly mentioned as one area related, which assess and evaluates power plant communication and other data transfer, but this research will not concentrate on that particular area of safety.

The relevant risks for the solution are evaluated during the risk assessments. Most important thing is to calibrate the risk matrix according (Figure 7) to the application and by using end-users risk acceptance criteria. This approach is chosen to verify end-users' capability to fulfil their own as well as legislative requirements. The additional adjustments needed are done during calibration of risk matrix, and there the best industry area wise practices for estimating risks and likelihoods shall be taken into account. Depending on the plant configuration and customer, parameters such as safety, environment and asset are used to determine risk. Additionally, reputation and asset where the latter one can include plant performance, equipment damage and other similar matters.

Product safety is wide concept that is mutual with between project stakeholders and surrounding environment. Importance of product safety grows even more when the surrounding area has industry or habitants close to the possible new power plant project. The most important phase, when planning the successful project is already in the sales phase where the contractual matters are discussed and decided, and the costs are determined. Layout and nearby industries can have crucial impact to the overall cost and time schedule when product safety matters are discussed in project execution phase and risk assessments are done in detail.

Likelihood \ Impact	Negligible	Minor	Moderate	Significant	Severe
Very Likely	Low Med	Medium	Med Hi	High	High
Likely	Low	Low Med	Medium	Med Hi	High
Possible	Low	Low Med	Medium	Med Hi	Med Hi
Unlikely	Low	Low Med	Low Med	Medium	Med Hi
Very Unlikely	Low	Low	Low Med	Medium	Medium

FIGURE 8. Example of risk matrix

Depending on the customers / end-users' risk appetite, the risk matrix categories can vary. Safety oriented customers can have higher limit for acceptable risk level than a one who is not safety oriented or the financing is arranged some other way than through insurance companies.

3.1 Health, Safety, Security and Environment

Health, safety, security and environment (HSSE) is the part which is mainly related to construction, operation, maintenance and decommissioning phase. HSSE supports all these plant lifecycle phases by providing instructions and methods how to do different tasks safely and not compromising himself or others during the task.

There are different legislative guidances' for HSSE depending on the country where the power plant is to be build and what is agreed with the end customer. Normally, these are ISO 14001 for environment, and OHSAS 18001 for occupational health and safety management. In addition, there can be customer specific requirements or local legislation requirements.

Similarly to product safety, HSSE has their own risk assessments with risk matrixes, which are done for tasks people are carrying out in any lifecycle phases concentrating to working procedures.
In the U.S., the OSHA law & regulations are giving the frame for health and safety
(OSHA Construction.)

3.2 Product safety

Purpose of product safety is to ensure that the end product is safe to use and does not cause harm for user or to the environment. Different risk assessments are one part of the product safety lifecycle management and they are done to ensure safety in design. Designer should use his evaluation as daily basis as a part of his design work and be critical towards own design. Many of the risks can be mitigated already in design phase. Directives in European Union (EU) lay a foundation to safety requirements for products, and their requirements are supplemented by applying their harmonised standards.

Risk assessments are needed to be done during design on iterative basis to mitigate risks. It is not possible to do this by executing one study for some design concept. It is often required to use more than one risk assessment method and in separate design phases to cover as much of hazards as possible. It is not either possible to fully remove probability of risk.

There are many different risk assessments for specific purposes and phases of the design. Some of them are meant for early design phase to screen possible hazards on layout. Some of them are to identify risks from plant processes that could cause process upsets. Purpose of these is anyhow the same, identify and set corrective measures based on the evaluation towards end-users acceptable risk level.

Some common methods which can be used in gas power plant applications and are common industry wide;

- Hazard identification (HAZID)
- Hazard and operability study (HAZOP)
- Fire (and explosion) Risk Assessment (F(E)RA)
- Layer of Protection Analysis (LOPA one method for safety integrity level (SIL) allocation)
- Quantitative Risk Assessment (QRA)

It is possible to analyse risks of the power plant or nearby industry towards the power plant by using different risk assessment. Some of these are concentrating for the layout to evaluate impact of different equipment location, and locating them in to right places based on their type of risk. Then, with the actual process risk assessments can be evaluated the process risks, e.g. is there enough safety shutoff valves, and with what partitioning or adequate level control with certain alarms and actions. Beside these there are also risk assessments to evaluate operability, machine-human interface, maintainability and much more.

Going further to more analytical methods, quantitative methods like fault tree analysis (FTA) can be used for investigating reliability and availability of a larger and more complex system. Similar qualitative tool is event tree analysis that can be used for root cause analysis (RCA) tool for hazardous event investigation, such as what all failures and tasks have been part of some hazardous event. With these sort of methods, overall plant configuration can be evaluated to reach certain reliability and availability for some estimated time period. Of course, in these the source for component failure rates and simulation tools have great impact for the calculation reliability.

Knowhow of different consultants are often from the Oil & Gas segments or in general from the process industry, and then they are comparing the requirements from there to power plant installations. This is not very reasonable since the risks are very different and more related to the reliability of power production to the network. Amount of fuel, which can be typically either liquid fuel oil or natural gas is considerable lower than in a process plant, refinery or oil rig where the typical guidelines have been developed.

Cyber security is one part of the overall safety of any plant communications. Figure 8 describes the principle that each network segment is secured from each other to prevent unauthorised access and modifications to communication. From safety point of view, especially the safety instrumented system (SIS) is critical in terms of controlling all safety critical functions in a plant. Cyber security is one part of the risk assessment that is assessed, where all the possible security threats should be identified and mitigated.

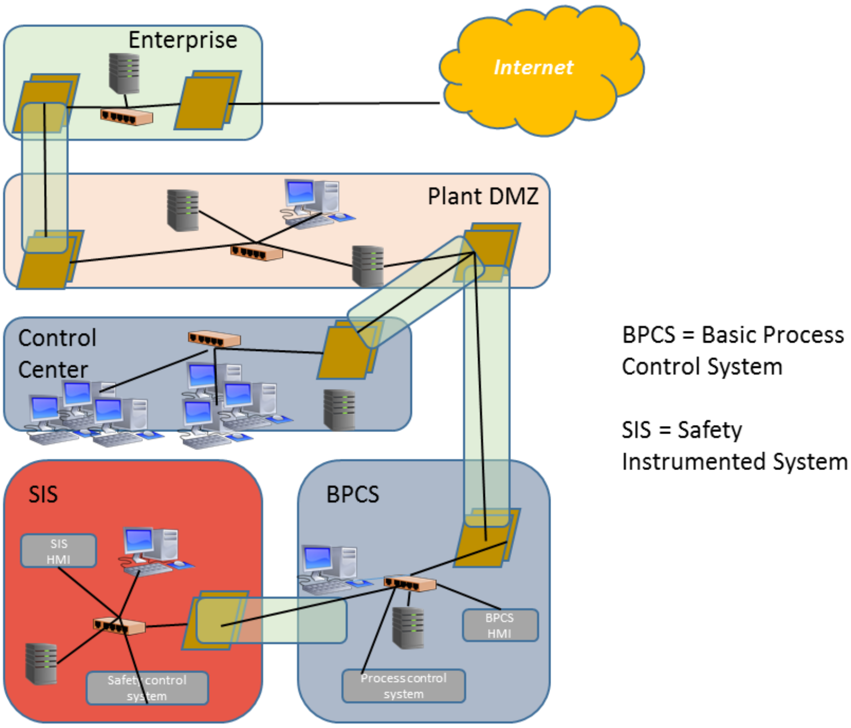

FIGURE 9. Example of cyber security topology segmentation for network security (Gilsin J. 2013.)

Cyber security has important part especially in critical plants that are either hazardous in case of accident, or critical part of operation of some bigger system. Such can be for example power plants for data centres and process industries.

Generally, it is important to do assessment on the layout and location for power plant installation. This is extremely important in the environments where exists nearby industries, inhabitants or environmentally important matters that can be harmed. If the plant is located next to process plant or similar that may have an effect to the power plant, it should be always included to the analysis so that the interfaces and hazardous impacts are investigated. HAZID can be done in very early phase to have screening of hazards that exist at the site and updated in later phase after design changes. In a later phase, these findings can be transferred for the QRA to do more detailed evaluation to have impact assessment of those hazardous events. HAZOP is done at least for the process system in basic and detailed design phase to identify risks during the design phase and after the design implications. Depending on the acceptable risk levels, which are end user's responsibility to provide as an input to the risk assessment, LOPA can be carried out to set additional risk reduction measures with safety instrumented systems with specific safety integrity level (SIL).

In relation to the interfaces, one essential part of complete electricity production is the transmission and distribution part which is one major interface in respect of safety, reliability and availability, and concerning all technologies of electricity production. Many of the risks related to this are downed power lines resulting from some external causes like storm, falling trees or vehicle crash. Similar to all risk assessments, the boundaries and interfaces for evaluation shall be determined and justified as reasonable, and for correct responsible parties. (EPA-600/7-77-016 1997, 33-35.)

SIL for specified function is always depending on the risk reduction needed when comparing the gap between identified risk and acceptable risk level. A specific SIL should not be determined as starting point of risk assessment, as it is the outcome of the risk assessment. In order to determine SIL level, at first it is needed to know the actual risk, how often hazardous scenario may happen, possible occupation near the risk, and is there some conditional modifier that can make identified risk even worse. After these can be determined what is the safety function subject to SIL, and what can be used to reduce the risk either as preventing or mitigating function.

3.3 Accidents in history of energy industry

One major accident cause in the gas turbine plants has been gas pipe cleaning in the commissioning phase. As part of the installation, gas pipeline to the turbine is installed as part of construction phase. Due commission and other reasons, debris can remain in the pipeline which requires cleaning of the pipeline to avoid causing gas turbine damage. Based on the history and accidents described in the following chapters, procedures are developed and now the appropriate ways are used to clean piping. The cleaning techniques are such as using pigging with air or nitrogen, air blows, nitrogen blows, steam blows, water and chemical cleaning. Common to these all was that it is not certain how much of gas is adequate to blow debris from the pipeline and this can cause extensive amount of gas accumulation in worst scenario. For example in the Kleen case, Siemens had provided the recommended Cleaning Force Ratio (CFR) which is needed to clean the piping but there was no upper limit for this, which resulted much higher gas release than was needed for the cleaning purpose.

One of the biggest gas turbine accidents happened 2010 at Connecticut, Kleen Energy Systems power station in U.S. The power plant construction was started in 2007 and it was scheduled to start supplying energy in June 2010.

> “The blast at the 620MW, Siemens combined cycle gas and oil-fired power plant occurred at 11:17 am, and was reported at 11:25 am EST. The plant's manager, Gordon Holk, said that contractors and other workers from O & G Industries, Ducci Electric, and Keystone Construction and Maintenance Services were at the site when the blast occurred. The explosion occurred at the rear of the largest building, the turbine hall, which was destroyed. Six workers were fatally injured during a planned work activity to clean debris from natural gas pipes at Kleen Energy in Middletown, CT. To remove the debris, workers used natural gas at a high pressure of approximately 650 pounds per square inch. The high velocity of the natural gas flow was intended to remove any debris in the new piping. During this process, the natural gas found an ignition source and exploded.” (CSB. Kleen Energy Natural Gas Explosion.)

Safe handling of natural gas is important factor in U.S. markets to be presented both in design and operation, as well as the complete lifecycle of the power plants. OHSAS did not have a clear safe handling procedures for natural gas at the time of Kleen accident. On the day of the incident, the plant personnel cleaning the pipe did not have a safety meeting to discuss about the risks of gas blows nor reviewed the blow procedures. Design and the gas blow pipe orientation caused the gas accumulation between the heat recovery steam generator buildings, which were all affecting for the gas dispersion. Kleen accident caused urgent actions from chemical safety board to develop procedures for safe handling of natural gas in OHSAS, and additions for NFPA and American Society of Mechanical Engineers (ASME). One of the developed standards related to this accident is NFPA 56 which is prohibiting the use of flammable gas to cleaning purposes. (CSB. Kleen Energy Natural Gas Explosion)

Comparable accident happened also in 2003 at Calpine’s Wolfskill Energy Center gas plant in Fairfield California, where was also performed a gas blow during the pre-commission phase. Similarly, there was a large confined space where the gas accumulated and ignited. Probable reasons considered in the investigation were the static electricity from the high velocity gas flow or from debris causing spark due collision to metal structure. Also in this accident, there was identified that safer methods for cleaning the pipe could have been used since natural gas is not the only way to clean the pipes. ((CSB Urgent Recommendations; Calpine.)

In 2001, there was also a gas blow accident in the commissioning at FirstEnergy power generation station in Lorraine, Ohio. Temporary short pipe was installed and for some reason the natural gas ignited due unknown metal spark causing high flames from the stack. Personnel damage was avoided but property damage was caused. (CSB Urgent Recommendations.)

List of actions were presented for all gas turbine manufacturers to address for customers for safe operation and maintenance of gas turbine plants. Later, there has been development in the NFPA committee to make more stringent requirements for the large gas piping purging to avoid similar hazardous scenarios. Also, alternative inherently safe ways to clean gas piping have been presented and required to be followed. (CSB Urgent Recommendations.)

There are numerous hazardous scenarios reported and collected for the database, which increases the reliability of investigation and development work. Collected incidents include both gas leakages which have created an explosion as a result of ignition, and other scenarios have been blade failures resulting as casing rupture and small fire. Fuel releases have occurred during the start-up from the loose flange and fuel changeover. One major matter to be noted for the explosion scenarios in this is that it has significance if the turbine is located onshore or offshore. Also there is always companies whom are not reporting the dangerous failure scenarios. (Santon R.C. 1997, 53-54.)

These examples show also the importance of the risk assessments; when design follows only the requirements for gas pipe cleaning process by using natural gas presented in the NFPA standard, it does not take into account all possibilities of hazardous scenario that might come up because of e.g. unexpected ignition sources. If there would have been a risk assessment covering also these hazards, this scenario might have been noticed, and blowout would have been done up to atmosphere and not towards the plant buildings.

There is possibility that all the accidents which have happened in the power plants are not reported publicly, which is normal silently accepted procedure amongst the industry. Process safety incidents are reported only if the occurred incident is process related. Break of coupling in turbocharger at a power plant without the appropriate usage of overspeed protections would not been reported as process safety incident, since it has no chemical product associated. All in all, it can be summarized that risk reporting is not aligned between industry areas. (AIChE, Process safety in power plants.)

Investigation and reporting of accidents, and related equipment failure is essential also for the development of data bases used for reliability calculation. Many industries are using the generic data bases most often collected from process industry to do quantitative risk analysis. For the company itself whom is delivering the product, the collected and correct data of the products from the field is more important. With the information, different scenarios can be justified and can be used to estimate the test and maintenance intervals to prevent hazardous scenarios as well improving the overall reliability of the product.

3.4 Legislation and codes

There exist a lot of standards, legislative norms and guidelines for gas turbines, which are used for the safe design of gas turbine applications and power plants. Some identified similar standards guiding gas turbine and reciprocating engine power plant design safety is listed in Table 1 for comparison. In both technologies, there are some standard state-of-the-art level of design which applies to legislative requirements, and if there are some local requirements which are more demanding and better, these are presented by the end-user. More comprehensive list is presented in Appendix C, though both of the tables are not complete so these should not be taken as reference without a further investigation.

TABLE 1. List of some product safety standards used in the gas turbine and reciprocating engine power plants

Standard Code	Standard Name	Gas turbine power plant	Reciprocating engine power plant
IEEE	The Institute of Electrical and Electronics Engineers (Multiple standards)	X	X
NEC	National Electrical Code (Multiple standards)	X	X
ASME	American Society of Mechanical Engineering (Multiple standards)	X	X
Machinery directive	The Directive 2006/42/EC of the European Parliament	X	X
ANSI EN ISO 12100 / ANSI B11.0	Safety of machinery - General principles for design - - Risk assessment and risk reduction	X	X
IEC 61508/61511	Functional safety of electrical/electronic/programmable electronic safety-related systems	X	X
ISO 7919	Mechanical vibration of non-reciprocating machines – Measurements on rotating shafts and evaluation criteria	X	N/A

TABLE 1. List of some product safety standards used in the gas turbine and reciprocating engine power plants. (Continued)

ISO 21789	Gas turbine applications - Safety	X	N/A
IEC 60079	Electrical apparatus for explosive gas atmospheres, Part 10: Classification of hazardous areas,	X	X
IEC 60204-1	Safety of machinery – Electrical equipment of machines – Part 1: General	X	X
IEC 61140	Protection against electric shock - Common aspects for installation and equipment	X	X
NFPA 37	Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines	X	X
ASME GT-90-GT-375	Experiences with external fires in gas turbine installations and implications for fire protection	X	-

National Fire Protection Association (NFPA) is a trade association of the U.S which develops and publishes consensus codes and standards for the purpose to eliminate death, injury, property, and economic loss due to fire, electrical and related hazards. These standards are adopted and used widely around the world. There are number of standards related to the fire protection, gas and explosion, which are used industry wide, but this research does not examine those in detail. (NFPA, Codes and standards.)

ASME is the leading international standards and codes developer for art, science and mechanical engineering. These standards and codes are developed to guide and improve public safety, health and quality. Market needs drive the standard development work, and there are more than 100 nations which are using the codes. (ASME, Standards and certification)

NEC is the national code for electrical installations, and it is adopted by the state law and local jurisdictions, which makes it more U.S specific compared to other codes and standards. NEC is also known as NFPA 70 and it is concentrating on the electrical installations and wirings. (NFPA, Codes and standards)

Based on accident reviews referring to earlier chapters, U.S. parties who make the guidance for safety in order to develop requirements further based on the accidents happened in the industry. The similar approach is also used in the European Union where major scale accidents have happened.

There are referring standards developed specifically for gas turbines based on hazardous scenarios which are dealing with hazards, such as the acoustic chamber and fuel supply explosion hazards. These are been presented below.

> “Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines, National Fire Protection Association (USA), 1994 (NFPA 37) is a fire protection standard but recognises the explosion hazard and recommends the provision of explosion relief for turbine enclosures, or the provision of "ventilation adequate to prevent a hazardous accumulation of flammable vapours or gases..." Adequate ventilation is not defined further. In the case of an engine handling hazardous material other than its own fuel supply, i.e. a gas turbine driven gas compressor, there is no alternative to the recommendation of explosion relief. The scope of this code is limited to engines and turbines not exceeding 7500HP, i.e. 5.6MW.
>
> Gas Turbines for Refinery Services, API Standard 616, Third Edition, American Petroleum Institute, 1992 (API 616) is essentially a purchasing specification but includes some relevant recommendations. It requires exhaust system purging, an automatic vent on any gas fuel supply, the minimum of flanges and flexible pipework, and insulation, or guarding, so that no exposed surface exceeds 74°C. (Since guards are permitted, this requirement is probably directed towards protection for operators rather than ignition risks.) It makes no specific reference to ventilation or other explosion mitigation means. A later similar code Recommended Practice for Packaged Combustion Gas Turbines, API Recommended Practice 1 IPGT, First Edition, American Petroleum Institute, 1992. (American National Standard ANSI/API RP 11PGT-92, Approved July 1993) is directed specifically at packaged plant. It refers to acoustic enclosure ventilation as having a purging duty but gives no safety specific guidance on it, and it extends the fuel gas supply shutoff requirement to two valves and an automatic vent.
>
> Publication IM/24, Guidance Notes on the Installation of Industrial Gas Turbines, Associated Gas Compressors and Supplementary Firing Burners, British Gas, June 1989. (IM24) is a broad code covering the whole installation from fuel supply to instrumentation. It refers to the need to provide adequate ventilation, and quotes 1m3/Vsec as the minimum for gas leakage ventilation. It refers to gas detection for some circumstances, but stresses that it should not be regarded as a substitute for good ventilation.
>
> Area Classification Code for Petroleum Installations, Model Code of Safe Practice Part 15, Institute of Petroleum, 1990. (IP 15) is a general area classification code for Petroleum Installations. It contains extensive discussion on the adequacy of ventilation, and a specific section on the ventilation and classification of turbine enclosures, or hoods, and the relevance of this ventilation to the prevention of the accumulation of flammable mixtures. Significantly it permits the enclosure to be classified as safe (unclassified) during normal

operation if dilution ventilation is present, recognising the effectiveness of properly designed ventilation in preventing accumulation.

The concepts of Adequate Ventilation and Dilution Ventilation are well recognised in area classification. Adequate ventilation is intended for applications where the probability of release is limited and unlikely to be sustained for a prolonged period, whilst dilution ventilation is intended to be high enough to dilute below the Lower Explosive Limit (LEL) any reasonably foreseeable leak. The concepts are discussed further in IP 15 and Cox, A. W., Lees, F. P., and Ang, M. L., 1990, Classification of Hazardous Locations, Institution of Chemical Engineers.. In both cases it is essential that there are no stagnant regions. Adequate ventilation, as defined, is not appropriate for releases that may be prolonged or where the probability of ignition is high, as is the case in both respects in an acoustic enclosure. IP 15 notes, in respect of dilution ventilation that "The design of the ventilation system must ensure that there are no stagnant regions and that the immediate mixing and dilution are as required." “(Santon R.C. 1997, 54-55.)

4 DIFFERENCES BETWEEN POWER PLANT TYPES

There are differences between the turbine and reciprocating engine power plants, but in some extent, they are similar with each other. Main differences are the power production equipment with supporting auxiliaries and amount of those in the plant. In turbine power plant, there are commonly from one to five turbine units depending about the operation mode and supplied production capacity. In reciprocating engine power plant there, can be engine-generator sets from 1 to 40 or even more depending on the operation mode and capacity that will be supplied. Because of this, the maintenance, maintenance scheduling and risk management is important in gas turbine plants since loss of one unit has significant effect for the plant operation and output. This is one of the major technology risk related matters that customers consider between the gas turbines and reciprocating engines. Reasons for the increased risk is the cost impact raised from number of equipment which require maintenance during the plant lifetime.

Another difference between these power production types is the control system, and that the operation mode of the plant is controlled. Turbine plants are at their best when operated as baseload power plants with the full capacity. Then the operation is continuous with less starts and stops including continuous power production. Process risk assessment, by identifying the critical deviations in the system, gives input to the reliability/availability analysis when unintended shutdowns and trips can be avoided. Reciprocating engine power plants are at their best in all different operation modes including baseload, peak load and emergency response. Reciprocating engine power plant can be started and stopped within short period of time (minutes). Different operation profiles can be developed for operation modes, e.g. some engines are running more than others as “forerunners”. Plant configuration can also be divided to partly run with baseload, and partly with peak load. These were also raised as technology risks from customer point of view. Operation of different modes and configuration of engines is unfamiliar for turbine operators.

In flexi-cycle plants, including steam turbine and condenser the plant configuration and its auxiliaries hardly differ, regardless of the configuration of the power production. Especially in the steam turbine plants, the cooling system has an important role in overall system operation. Cooling system is controlling the steam temperature which has impact on the steam pressure, and when variating too much may cause damage to the system. Also, breakage of cooling water system may lead to cooling water leakage to steam condenser, which would further cause liquid carryover to turbine and damage the turbine blades.

Turbine plant requires more space to be fit in the surrounding environment compared to the reciprocating engine power plant. This is important factor when evaluating the plant layout and how it can be built, for example near the industry or community to provide safe and environmentally friendly solution to mitigate possible risks. Size of the turbine or reciprocating engine power plant was not raised as a risk factor, but other environmental matters like noise and emissions are normally discussed in the sales phase.

4.1 Common risks in both power plant types

Common risk in both power plant types is variation of the fuel supply that is connected to the plant. Risks related to the layout are similar in both power plant types, as both gas and fire can cause escalating major hazards. Due higher volumes of fuel in turbine power plant, the consequence is more severe. In relation to this, the power plant interfaces are equally important in both power plant types.

From technology point of view, the risk causes are similar, e.g. overspeed, high gas pressure, and loss of power. In the both technologies, the electrical and compressed air systems are crucial due the plant control. Both have impact on availability and reliability of the power plant, if there is failure that can cause unintended shutdown.

The previous two paragraphs were about actual product safety related risks which were araised in literature review. Risks and safety function requirements for turbines were presented both in standards and accident investigations. In the interviews, typical risks presented by customers focus more on the Ex-layouts and how these are considered in the plant design.

4.2 Turbine power plants

In this research, the focus is in gas turbine power plants since the reciprocating engine technology also uses fuel gas technology. Other alternate turbine technologies are briefly described below, and the overall content concentrates for safety and differences with the reciprocating engine technology. Figures 9 and 10 present simplified processes of gas turbine and combined cycle gas turbine cycles.

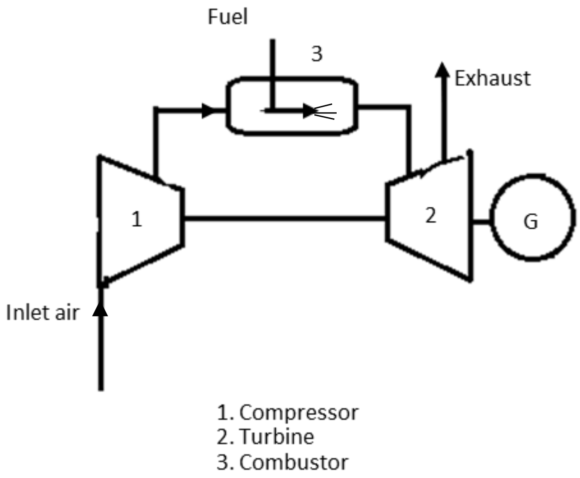

FIGURE 10. Simplified picture of gas turbine cycle

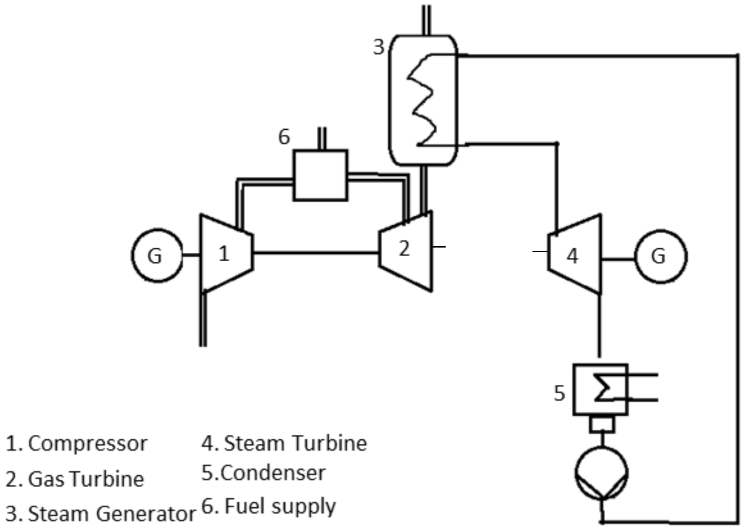

FIGURE 11. Simplified picture of combined cycle gas turbine (Kehlhofer 1997, 3)

Reciprocating engines are often used to deal peak loads due to their fast start-up time, low initial cost and short delivery time. In terms of start-up times for gas turbines, the time frame is around 30 minutes and design life of approximate 3000 starts depending on the turbine type (Lipiak 2006, 3,5). Annual start-up amounts are much less than with reciprocating engines and the start-up time is considerable longer. This is one of the reasons beside efficiency and unit output, why turbine technology is most often used as a baseload. Gaseous or vaporized fuel is injected into a combustion chamber together with compressed incoming air. The resulting high-pressure and high temperature exhaust are used to drive the turbine which in turn drives both the generator and the compressor (Giampaolo 1997. 71-72, 79-82.)

A combined cycle gas turbine power plant (CCGT) is flexible and more efficient turbine plant. It is similar to gas turbine plant by its design with the difference that there is waste heat recovery system collecting the steam from process in to the boiler driving steam turbine that generates electrical power. Generalised turbine plants consist of main power production units, supporting auxiliaries, electrical equipment and control system similar to reciprocating engines. The differences are amount of units, operating modes and process values such as operating speeds, and the fuel supply pressures and capacity. (Giampaolo 1997. 85-104; Kehlhofer 1997. 171-221.)

Due the size of gas turbine and turbines in general, the required inertia and torque required to start rotating of the turbine shaft requires external power for the start-up. There are different solutions, but commonly diesel motors are used for this, and with the gearbox and clutch the disconnection is enabled after turbine start and speed increase. (Giampaolo 1997, 85-89)

4.3 Safety in gas and steam turbine power plants

In this section, the main safety risks are described. In addition, possible and scenarios happen in history is reviewed. The review is based on the available material by the hazardous accident investigation reports by safety authorities, available risk assessments and related literature.

Highest risks are related to the turbine itself. The highest single risk considering the damage either in asset value, safety, reliability or availability is related to the over speed and breakdown of turbine. This is because of the high speed of turbine (normal operation speed around 3000 rpm) during operation and the overall rotating mass of it (10 to 20 tons depending on the gas turbine size). Loss of over speed protection would mean loss of the only safeguard against this scenario, and in case of failure it would cause damage to the plant, operators and personnel depending on the plant setup. Other significant risks in different parts of the systems based on the Hazard and Operability study are related to the high pressure that can cause fatality, loss of production or severe damage to the equipment depending on the fluid e.g. steam or gas. Another high-risk item is related to the start-up of the system. Also most of these risks are related to the high pressure in the system creating a risk for steam explosion or substance carry over in the system either due to the system operation as automatically or manually by operator.

Generally, the risks are either personnel or asset related risks. Asset related risks are caused mainly by turbine damage since it is the most expensive and most critical item for the plant operation. Delivery time for turbine is also long, which will have great impact for the plant availability in case of failure.

The most severe accidents which may occur at a gas turbine plant are explosion, asphyxiation and ruptured lines. Explosion, with possible sub-sequent fire, can occur in the turbine, compressor combustor and recuperator. Explosion and fire typically occur because of fuel mishandling or component failure. Probable scenario related to gas is the accumulation of flammable gas within the turbine and associated exhaust system, which is ignited by the combustion process itself example in star-up phase. This is common hazard in any gas related application and can be mitigated if identified in the design and corrective measures are allocated. (Santon R.C. 1997, 53.)

Power failure may result from explosions from electrical malfunctions, breakdowns, circuit overloads or human error, and from accidents involving transmission and distribution of electricity. (EPA-600/7-77-016 1997, 33, 229.)

In gas turbine and steam plants, explosions may occur in the fluidized bed-combustor system with ejection and dispersion of the bed contents. The containment vessel in an atmospheric fluidized bed system could rupture as a result of accidental pressurization, whereas pressurized vessels can suffer burn-through and explode. Both atmospheric and pressurized fluidized bed systems, fired with coal, also run the risk of fire from spontaneous combustion. An additional accident which may occur in gas turbine plants is asphyxiation from toxic working fluids. Two developmental gas turbine systems, integrated low-BTU gasification and refined coal, could release toxic substances such as hydrogen sulphide, carbon monoxide, and coal tar volatiles from leaks, pressure ruptures, process failures, or by human error. The fluidized-bed coal combustor could release alkali metal hydroxides through leaks, pressure ruptures error or spilling. In the condenser or boiler, an accident could occur, which would result in an alkali metal water reaction causing fire and explosion. (EPA-600/7-77-016 1997. 229; Santon R.C. 1997, 51.)

Gas fuel supply for a gas turbine requires a high pressure which can be example for 6MW unit around 8 to 20 barg and a 40 MW unit can take 10 tons in hour up to 30barg. Piping design can be challenging since the design is dependent about unit size and each chamber might require multiple main fuel supplies, and also alternative fuel supplies. For example, for 250 MW unit the design may include over 200 flanges, 90 flexible hoses, 18 valves and 8 bellows all operating at 20 barg and liquid fuel supplies may operate around 60 barg. Absence of isolating valves in fuel supply system causes similar problem as in process industry that in assembly or maintenance phase it is not possible to test final connection of the piping due difficult access. Probable scenarios (to happen once in a two-year period) related to the fuel pipelines are the leakages due to maintenance and also from random vibrations. (Santon R.C. 1997, 52.)

Similarly, to reciprocating engine power plants the site, access, ventilation, fuel pipework and explosion relief design shall be justified with the appropriate risk assessments, and further, implement the needed design solutions. Site selection is affecting to the plant design through many matters such as natural ventilation. In addition, the environment having emission and noise limits need to be considered. Gas accumulation to the plant and engine / turbine hall affect to the ventilation design and to the gas detection measures. Access to the plant and different areas where operator can be exposed to hazard shall be always minimised and only permitted according to designed procedures. (Santon R.C. 1997, 57)

Detectors should be located near potential sources so that the leaks are detected. Ventilation and plant shutdown procedures with possible interlocks shall be designed as safe to minimise further escalation. Explosion relief valves are recommended as risk reduction measures if the dilution ventilation is not practicable, as relief valves has been justified as proven reliability. Location of these can be either outdoors or indoors depending on the site layout. To minimise subsequent damage due the relief valve opening and fire, emergency shutdown with fuel supply shutoff can be considered during the risk assessment. Important matters on fuel pipework is the amount of connections to minimise all possible leakages. Double containment and relevant safety shutoff valve design should be considered. (Santon R.C. 1997, 57-59.)

4.4 Components

In the following chapters, main components of the combined cycle gas & steam turbine power plants are gone through andsome of the challenges are identified. For example, what limitations those might have and what are the options in between relevant system for plant to be selected to achieve best and optimal plant for use.

4.4.1 Gas turbine

The most important, expensive and largest single component in the turbine plant is the gas turbine itself. The both combined cycle and steam turbine technologies use similar type of turbine technology and from these the combined cycle has become competitive only because of rapid development of the higher gas turbine inlet temperatures. Also, the compressor unit has been developed during the time and by now it can take higher mass flows and pressure ratios enabling higher power outputs reducing costs and improving the overall efficiency. (Kehlhofer 1997, 171.)

Because of fast development of the gas turbines, they have faced some negative impacts in the availability. Turbines have been primarily developed for use as independent units. Due to fuel cost rise, the development for improving efficiency has been fast, which has been the cause for high turbine inlet temperatures that affects availability. Today these issues have been fixed and reliability and availability has increased enabling in large base-load or medium-load combined cycle plants with the as high availability as conventional steam turbine power plant. (Kehlhofer 1997, 172.)

Another great impact and concern is the fouling of compressor which operates in an open cycle drawing air which is always a bit dirty despite the air filtration. Turbine fouling is a problem if dirty fuels are used. These have become higher concern than the previous inlet temperature problem. Compressor is impossible to keep completely clean, and this eventually causes losses in output and efficiency, that are greater in single-cycle than combined-cycle due to the fact that steam turbine can be used for recovery of losses. Two different methods have been used to recover efficiency losses which are (Kehlhofer 1997, 172-179.)

1. Dry cleaning using nutshells or rice
2. Washing

Washing has been the preferred method since it does less damage to the compressor blades protective coating. In both cases, it requires shutting down and cooling to have efficient clean-up, which means approximately 24hrs shutdown. (Kehlhofer 1997, 172-179.)

Turbine fouls mostly because of ash in contaminated fuels. Another important factor is the additives used for high temperature corrosion prevention. Fouling is a problem especially in base load plants. In medium load and peaking load plants, the self-cleaning affect by the start and shutdowns. Comparable low speed washing of cooled turbine and compressor enables to recover 50-80% of losses. (Kehlhofer 1997, 179.)

4.4.2 Compressors

Used compressors are either centrifugal design or axial design type. Compression ratios have been significantly increased from the past. Compressors provide the high pressure, high volume air / gas flow to turbine providing the power output for the process. Depending on the size of the unit, compressor type will vary between axial and centrifugal, where axials are used in bigger applications. (Giampaolo 1997, 52-64.)

4.4.3 Waste heat boiler

Waste-heat boilers connect the gas turbine to gas and the steam processes. There are three main types which are presented in the following chapters.

Both conventional and fluidized bed boilers are a serious source of hazard because of potential explosion risk. Boilers are operated with a high pressure which can present an explosion hazard. Explosion probability will be increased by high temperature and erosions. Beside these, the fire and coal dust explosions increases the pressure of boiler multiple times. Tube rupture in the boiler may occur causing some equipment damage with shutdown. (EPA-600/7-77-016 1997, 229.)

4.4.3.1 Waste-heat boiler without supplementary firing

Waste-heat boiler without supplementary firing is basically a heat exchanger. Operational requirements set difficulties for this system, and one of the major concerns is the short start-up time of the gas turbine. Waste heat-boilers without supplementary firing can be built based on steam generator with forced circulation or natural circulation. (Kehlhofer 1997, 180.)

Combined cycle plant gain advantages from the forced circulation because of its vertical design, fast start-up, suitability for designs with a low pinch point and smaller sensitivity to steaming out in the economizer. Major benefit of natural circulation boiler is that no circulation pumps are needed. (Kehlhofer 1997, 180.)

The optimum waste heat boiler must meet the following conflicting-conditions:

- Ratio of waste heat application must be high (high efficiency)
- Pressure losses on the flue gas side must be low in order to avoid losses in both output and efficiency of the gas turbine
- Low temperature corrosion must be avoided
- Acceptable pressure gradient during start-up must be wide

These conditions are difficult to achieve simultaneously. Because of the temperature difference there will be heat transfer (negligible because it happens with radiation). Surfaces required for the heat exchange would be large for good rate of waste heat utilization, which means pressure losses. This problem can be solved with small diameter finned tubes but its thermal capacity will be small and it favours quick changes in load. (Kehlhofer 1997, 181.)

Problem in the waste heat boiler design is concerning the surface and its area. Operational issue is the ability to respond fast for start-up of gas turbine. Cost of the waste heat boiler is depending a lot of the surface installed. Area of the evaporator increases exponentially as function of temperature (differential decrease), while the increase in steam generation is only linear. Too large heat exchanger surface can cause pressure losses on the flue gas side reducing a bit of the output. (Kehlhofer 1997, 182.)

Operational issue is that there are large differences in specific volume between water and steam at low and medium pressures, which cause large amounts of water to be expelled from the evaporator at the start of the evaporation process. If the drum cannot take this water, there will be great losses of water through emergency drain on each start-up. The gross volume of the drum should therefore be 1.5-2.5 times as great as the volume of the evaporator steam in normal operation. Volumetric change can be controlled with employing recirculation so that at least no steaming out occurs in the economizer.
(Kehlhofer 1997, 188.)

4.4.3.2 Waste-heat boiler with limited supplementary firing

Principle of this operation is similar to waste-heat boiler without supplementary firing. Firing itself has various design options. The principle is mostly used technology when natural gas is used, since it allows uniform temperature distribution after burners and the radiation to the combustion chamber walls will be limited. Burners are available for burning oil also, but since it causes more problems than benefits it is preferable to look other solutions. Evaporator is consisting of natural and forced circulation processes. Major advantage of boiler with cooled combustion chambers is its operating flexibility. Control of the supplementary firing enables the maximum temperature to be more than 750C. Benefits comes up in co-generation applications and such where broad control range is required for the process steam flow at different gas turbine loads. (Kehlhofer 1997, 189-192.)

4.4.3.3 Steam generator with maximum supplementary firing

With this type of steam generator it is not correct to speak about a waste heat boiler. This is because the heat content of the exhausts is small in comparison of the output of the firing in the boiler. Exhaust gases from the gas turbine are used primarily as oxygen carriers. Design is closer to a conventional boiler with the exception that there is no regenerative air preheater, because exhaust gas temperature is already high enough. Economizer is needed to reduce the temperature of exhaust gas after the steam generator to a normal temperature. The best arrangement divides the feed water between the economizer and the high pressure feed heaters. When gas is used as fuel, additional low pressure part of flow economizer improves efficiency. The fuel burned in the boiler may be oil, gas or pulverized coal. (Kehlhofer 1997, 192-193.)

4.4.4 Steam turbine

Steam turbine must possess the two main characteristics which are high efficiency and short start-up times, and these are concerning all installations without supplementary firing. Short start-up times are important for combined-cycle plants which are often medium-load units as peak plants having daily start-up and shut-downs. (Kehlhofer 1997, 193-197.)

4.4.5 Generators

Most of the gas or steam turbines used in combined-cycle plants are connected directly to the turbo generators. The typical turbo generator types used in combined-cycle plants as presented by Kehlhofer (1997) are listed below;

- Air-cooled generators with an open-circuit cooling system
- Air-cooled generators with an closed-circuit cooling system
- Hydrogen-cooled generators

Preferred option has been the open-circuit air cooling because of costs and cooling requirements, but it is vulnerable to fouling and noise. Closed-circuit systems have been built for capacities up to approximately 200MV A. They are reasonable in cost and also problem free in operation efficiency being high. Hydrogen cooled generators have possibility to achieve even higher efficiencies but they need additional design, auxiliaries and monitoring equipment, which are increasing the overall cost. (Kehlhofer 1997, 197-198.)

4.4.6 Electrical equipment

Combined-cycle gas turbine plant is similar with conventional power station containing some turbines what comes to the typical single-line diagram. Power for the station operation can be supplied either from each gas turbine or from the steam turbine separately, but the gas turbines can provide needed power for the steam portion auxiliaries also. It is common in smaller combined-cycle plants (less than 100 MW), that there is no medium voltage (MV). Related auxiliaries are though equipped with low voltage (LV) motors. (Kehlhofer 1997, 198.)

4.4.7 Control and control equipment

The control system is the most important part of the power plant also in turbine plants as it is in all industrial applications. Its purpose is to control and protect enabling safe operation as well gather the data. Standard gas turbine is supplied as fully automated machine. The steam process requires to take interfaces and calibration of process in to account so that these are all corresponding each other. The plant mechanical part and processes are simple compared to control system since these are making the plant complex as whole. (Kehlhofer 1997, 198-201.)

Hierarchic and distributed structure for open and closed loop control systems is best ratified for the complete process. This will make it possible for simple planning, commission the plant in stages and raise the availability of the power plant. (Kehlhofer 1997, 201.)

Kehlhofer (1997) introduces drive level and the functional group level, which both have specific functions. In the former, all individual drives are controlled and monitored, and safety devices in the switchgear act directly on the switches and the relays. All these signals are sent both to the logical control circuits of the drive level and to the higher hierarchic levels. On the latter, the individual drives for one complete fraction of the process are gathered together into functional groups. The logical control circuit on this level comprises interlocks, automatic throw switches and preselection of drives. (Kehlhofer 1997, 198-201.)

The turbine protection control is used to monitor speed, temperature and vibration, which are such critical process parameters that can cause hazard with severe consequence to the operation, asset or / and for personnel. Similar to all industries, different levels for alarm and shutdowns are used to allow operator action if there is time to perform needed action or the plant operation is more critical than automatic shutdown. Overspeed protection is one example function that is automatic due to its extremely fast occurrence and severity. Its typical causes are excessive fuel flow or loss of load (as a result of coupling failure). (Giampalo 1997, 81.)

Temperature protection is used to protect against excessive high temperature but also to protect excessive temperature spread. Use of multiple temperature sensors is based on the protection of excessive temperature spreading. (Giampalo 1997, 71.)

Due to severity of consequence and possibility of failure, turbines usually have safety instrumented system with multiple functions which are as part of their protective control functions. Such functions are, for example, overspeed protection of the turbine, flame monitoring, electrical gas heaters control and condenser protection. (VDMA 4315-6 2014.)

4.4.8 Other components

Beside all the above main system components discussed in earlier chapters, there are multiple supporting auxiliary components for the turbine plants which are listed below;

- Condenser
- Cooling system
    - Direct cooling using river or seawater
    - Indirect cooling with a wet cooling tower (need of water approximately equal to condensate)
    - Direct air cooling in an air condenser (no water needed)

- Feedwater tank / deaerator
- Feed and condensate pumps
- Condenser ejector system
- Water treatment
- Compressed air supply
- Lubrication system
- Ammonia injection system for NOx control
- Flue gas bypass (requires additional care for flue gas damper design)
- Steam turbine bypass

Cooling water system has important part of the overall efficiency and operation. For example clogging of the system can lead the overall system shutdown because of reduced flow in the system. Also the turbine system is vulnerable for environmental temperature variation where normally higher temperature can reduce overall efficiency of cooling system. This can lead, for example, lube oil temperature increase and potential failure of steam turbine. (HAZOP report.)

Lubrication system has the function to provide adequate lubrication between the rotating equipment, such as bearings surfaces, at the same time providing cooling of these. There are different types of lubricating oil, as well as bearings which can have effect for the lubrication oil function. Typical lubrication oil system consists of a lubrication oil tank, redundant pump units, regulators, oil filters and oil coolers. For the cold environment, oil heating can be provided to maintain certain viscosity. Redundancy of equipment is to provide back-up if one fails, and the regulators to maintain constant pressure for the system. (Giampaolo 1997, 94-100.)

Selective catalytic reduction (SCR) is used as part of the exhaust gas system for NOx emission removal with the ammonia injection. The NOx removal process and the system operation depends in some extent about the plant operation profile as well as the gas content.

4.5 Reciprocating engine power plants

Reciprocating engine power plants may consist of multiple engine-generating sets with their auxiliaries. Plant size can be almost anything needed by application. Typically these are from small 20MW power plants to more than 300MW power plants measured as output. Main risks in the reciprocating gas engine power plants are the gas handling and possible leak and explosion scenarios other than actual equipment or engine failures. Typical small gas power plant can be seen in Figure 12.

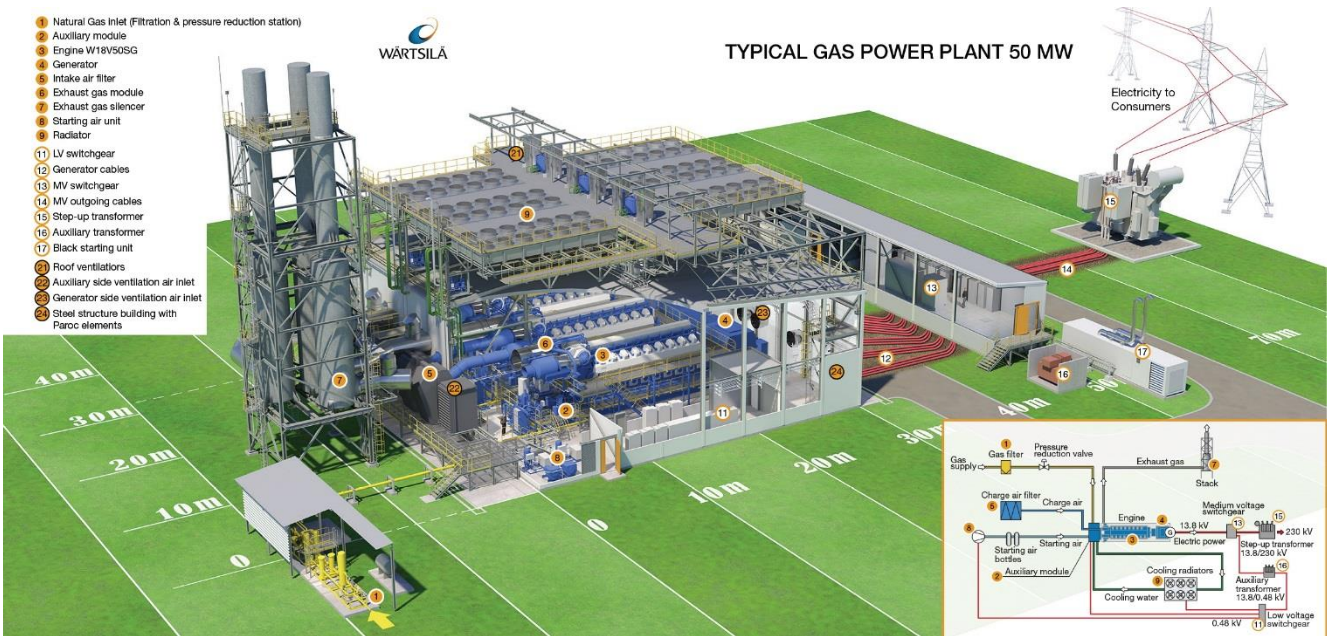

FIGURE 12. Typical smaller gas based reciprocating engine power plant layout. (Wärtsilä).

Number of engines guarantees back-up for each other for example during maintenance periods. Size of the engine power plant site area is dependent of unit amounts and used fuel type which affects to the fuel supply type.

4.6 Safety in reciprocating engine power plants

This chapter examines the main safety risks which are possible to happen. Also, some scenarios that have happened in history of reciprocating engines power plants industry are presented. Review is based on the available material by the hazardous accident investigation reports by safety authorities, available risk assessments and related literature.

Highest safety related risks in the reciprocating engine power plants relate to the fuel supply that is provided to the power plant. Depending on the power plant configuration and amount of the reciprocating engines, reciprocating engine can be equal risk in means of availability and reliability.

Fuel supply is one of the biggest risks for availability and reliability, because there is usually one main gas pipeline to the site where it is divided depending on the plant configuration. This way gas is carried to each engine or sets of engines. Rupture of pipe may lead to a significant gas cloud which can cause fatality of multiple persons. The dual fuel reciprocating engine driven power plants can be operated with alternative fuel if operator sees it acceptable in terms of safety. This has significant effect on the reliability and availability of the power plant. In liquid fuel power plant, the supply risk is related to the fuel tanks and the fuel pipelines to the individual reciprocating engines or set of units. In a big power plant consisting of multiple engines, usually more than ten, fuel amount at site can be great and it requires certain fuel transportation with operator interaction.

Fuel supply risk in the engine power plant is comparable to the risk in the gas turbine power plant, but the volume and gas pressure in the fuel pipeline is much smaller than in gas turbine power plant. This means that the consequence severity in case of accident is smaller than in gas turbine power plant.

Depending on the reciprocating engine configuration of the power plant, total loss of one reciprocating engine is not so crucial when having multiple units. If we have only two or three units, then it has more impact for the overall output and plant availability. In a power plant where exists more than ten or 20 reciprocating engines, there can be one or two units operated as forerunners to detect possible faults and allow operators to do needed modifications on other units to avoid lastly identified scenario. Most severe scenario of engine failure is related to overspeed and breakdown of engine. However, a damage it could cause, is less severe compared to gas turbines because of slower speed (between 400 - 1000 rpm), and the much smaller component mass.

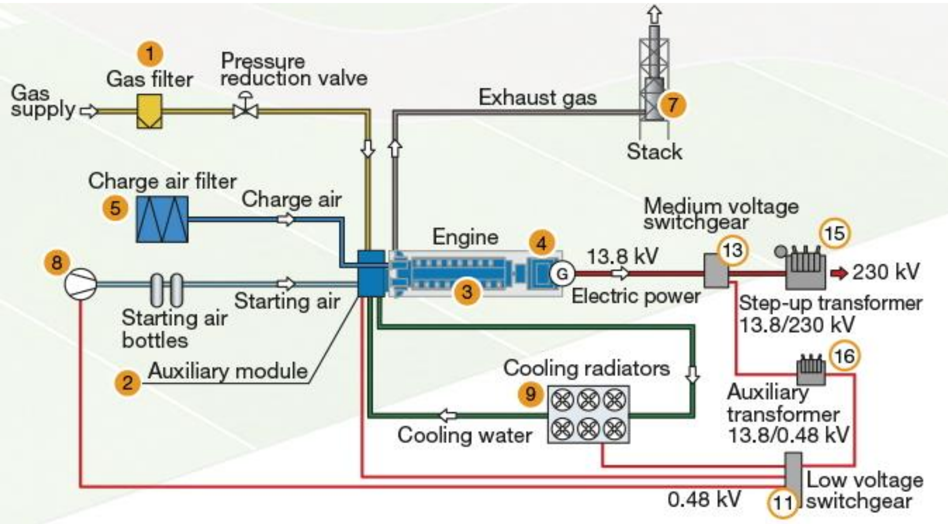

FIGURE 13. Simplified flow diagram for gas based reciprocating engine power plant (Wärtsilä).

Figure 13 presents simplified flow diagram for gas based reciprocating engine power plant. Typical units for power production with supporting auxiliaries and power distribution are shown. Amount and setup of the units are dependent on plant configuration. Following chapters describe these single units more in detail.

4.7 Components

In the following chapters, main components of the reciprocating engine power plants are described, and some of the challenges and limitations they might have are identified. This includes also review of the options in between relevant systems for plant to be selected to achieve best and optimal solution for customer needs.

4.7.1 Reciprocating engine

The reciprocating engine is the most important and expensive single component in reciprocating engine power plant. It is the power production unit supported by multiple auxiliary systems and rotating the generator to produce electricity. Reciprocating engine have multiple internal processes from fuel injection to cooling water process. Similar to gas turbine, overspeed is the most severe single risk possible to occur from similar reasons as in turbine. As well for other functionalities, there are protective functions in engine to support safe and reliable operation.

4.7.2 Generator

The generator is as important part of the power plant as the reciprocating engine since its task is to convert mechanical energy produced by the reciprocating engine to electrical energy. These are commonly 3-phase synchronous machines which operation is based on pulling force between two magnetic fields; stator and rotor windings. Generator protection can be done with different type of protection relays.

4.7.3 Fuel handling system

Fuel handling system can be either based on liquid or gaseous fuels. Depending on the setup, it will have an effect to the supporting auxiliaries and fuel storing at site. In pure gas power plants, the liquid fuel handling and storing system is minor since the light fuel oil is then only supporting gas as a back-up fuel.

Gas fuel power plant will have a light fuel oil (LFO) storing, gas pressure reduction station, gas distribution and engine specific gas ramp unit for fuel gas control. Process control can be done in different ways, which can have an effect for the emergency shutdown and venting, principles depending on the plant operation mode and end users' requirements.

Usually, fuel gas comes from some supply with a higher pressure, around 40 barg and then it is reduced to lower level, around 10 barg. After this, the gas is distributed to individual fuel gas control modules and engines.

4.7.4 Compressed air system

Compressed air system handles both control and instrumentation air for the power plant, including all auxiliaries and engine generating sets. There are separate compressors and air reserves for control and instrument air purposes in the plant to maintain adequate air pressure for all concerning functions. Dryers and filters are in the system to collect possible condensate water to enable clean air. Compressed air system is enabling functions in systems to be controlled, and therefore a loss of the system could cause severe hazards, in the worst case.

4.7.5 Lubrication system

Lubrication system is built up differently depending on the amount of engine generating sets in the power plant. Sizes and capacities of tanks and pumps are essential for adequate lubrication oil distribution as well as the separation and cleaning processes. If simplified, lubrication oil is pumped from the tank by distributing lube oil to the individual engine generating sets. Similarly, the used lubrication oil is circulated from the engine generating sets in to the used lubrication oil tank. Main components associated in this system are pumps in separate pump units, filters and valves.

4.7.6 Cooling water system

Cooling water system provides adequate cooling for the engine generating sets in the power plant. Furthermore, the system decreases charge air temperature to an optimal level for the engine generating sets cylinders, and cools the lubrication oil. Depending on the plant configuration, ambient requirements and power plant needs, there can also be heat recovery part of the cooling system. High temperature water circulates through an engine to the cooling tower radiators, where low temperature water flows back to the engine. Depending on ambient, there are heaters and coolers in the circuit for temperature optimisation.

One of the main component in the cooling system is the expansion vessel to even the temperature and pressure variation of the circuit, pumps, heaters, valves and maintenance water tank for emptying and refilling purposes. Number of radiators in the cooling water system depends on the power plant size, application and ambient temperature. Depending on the configuration of the power plant, it is either called Flexicycle power plant, or combined cycle power plant when it is connected to steam turbine. Several other functions can be integrated into the cooling system, such as the condensers, steam turbine and other related auxiliaries.

4.7.7 Electrical equipment

High voltage (HV), MV and LV systems comprise the overall electrical layout for the power plant. Possible risks in the HV system are for example, overvoltage caused from the HV side or from the generator that could cause damage to step-up transformers applicable also to the turbine technology. Most of the risks also in MV and LV systems are related to the under and over voltage, or current similar to HV system. Systems that can be affect by these, are varying from generator to lighting.

Electrification of the plant can be provided either from the engine generating units, direct current (DC) supply or from the black start unit i.e. diesel generator. In the worst case, failure in one of these can cause damage to consumers and damage the back-up supply.

Protection can be done with different type of protection measures depending on the scenario. For example, high voltage spikes can be prevented with protection relays. Another example is scenario where breakers will disconnect electricity supply from systems in case of fault.

4.7.8 Control equipment

The control system is the most important part of the power plant as it is in all industrial applications. Its purpose is to control and protect as well to gather the data. The plant's mechanical part and processes are simple compared to control system since these are making the plant complex. Control part can be divided roughly to engine-generator control and power plant control. Both are communicating with each other through interface and forming an ultimate system for power production. Main differences compared to the gas turbine power plant are the control modes of the power plant, operation of different configurations of engines depending on the application profile, and the remote control of power plant.

Control systems are based on open and closed loop circuits, and having an distributed structure for different parts of the power plant control. This enables easy planning, phase wise commission and raises the availability of the power plant.

Control and protection functions are separated in all levels, which are engine, generating set, switchgear and power plant levels, to provide independency, and high level of safety and availability during the power plant lifecycle. Both high end technology and hardwired solutions are used based on the criticality of the control functions.

Normally, reciprocating engine power plants does not have SIS. It only can occur if the end user has a high risk acceptance criteria, especially for highly unlikely hazardous events meaning that probability of acceptable hazardous event shall be extremely rare.

4.7.9 Other systems and components

For the emission control there is separate SCR system similar as described in the turbine section.

Water treatment and oily water treatment systems differ project wise. There are few essential factors which have an effect to water treatment system design. Raw water quality is important when the configuration of system is decided. In addition, the configuration of the plant needs to be known, and especially, the quality of the treated water has to be reached depending on the consumers. When boilers are used, the treated water must be ion free and therefore reverses osmosis is used to remove the salts. Purpose of the water treatment system is to produce qualitative treated water with adequate amount for consumers in the plant. Oily water treatment system purpose is to clean oily water and other impurities and particles from the oily water before it is transferred to the sludge tank.

Condensers, steam turbine and other related equipment and auxiliary systems for improved overall efficiency can be in a combined-cycle power plants.

5 RESEARCH PLAN, QUESTIONS, TARGET AND METHODS

In this work, U.S. market situation of reciprocating engine power plants was under the interest. The focus was in the product safety, and what is the significance of the product safety to the competitiveness in the markets. The research questions were developed to base on the interest and the target was to bring up the current situation of the market and what would be the needed changes. Another subject was to investigate why the customers have certain attitude for technology risks in reciprocating engine based power plants compared to gas turbine power plants.

In this section, the research plan, research questions and targets are described. In addition, used methods are introduced. Selection of research question was based on the need to investigate U.S. market situation from reciprocating engine power plant perspective and how product safety could be used in that. As target with this research was to bring up current situation and how it would need to be improved. Another subject was to investigate why the customers have certain attitude for technology risks in reciprocating engine based power plants compared to gas turbine power plants.

This chapter will describe the research plan, research question and its target as well the used methods.

5.1 Research Plan

Before the question could have been composed, a basic knowledge both of power plant types and the overall U.S. markets was needed. This is introduced and discussed in sections 2.5 and 4. By using this information and various business cases as a background, the interview questions were formed. At the first, the plan was to interview customers but because of challenges to find credible interviewee, the plan was changed. The persons from company with close operations with customers and with both technologies were chosen. The challenge was to find enough personnel, so the number of the subjects was not decided at the first place. It was clear to involve different expertise areas to cover all related aspects for this research work.

Basic knowledge would be investigated from both power plant types as a basis, and also the overall U.S. market needed to be looked into. Business cases were discussed to be selected from basis to support the research and based on the background review and business cases the interview questions were formed.

Research methods were selected from the basis that there was not too much information available from the product safety aspects in U.S. in general or either in customer level in that market area. Also, the business itself is quite specific as well the product safety area which in some extent restricts the available information.

5.2 Research question and target

Research question was how the technology risk can be mitigated between the gas turbine and reciprocating engine power plants. Also, the possibility to improve competitiveness with product safety was investigated. The research question was selected because previously mentioned aspects are ongoing matter in many ways in the organisation, and product safety as such has significant meaning in different business divisions. The requirements from product safety are going to be more stringent and adopted by industry segments which normally haven't been as stringent. Also, the market situation is tough in energy business with gas turbines. Product safety matters are especially raised within safety oriented customers and demanding energy applications.

Aim of the research is to investigate what is the technology risks the customers have and what is the current market situation in respect to the product safety requirements in the selected market area of U.S. This means that the research includes the investigation of U.S. energy market, relevant legislation and how the product safety requirements are composed from it. Comparison and differences of the technologies, gas turbines and reciprocating engines are one major part of the research.

Based on this literature review, questions for the survey have been created with supporting business cases. Questions have been iterated during the research as described and reasoned in the chapter 5.4.

5.3 Literature

Literature contains material available in internet, publications and internal material from Wärtsilä. These are described in Figure 14.

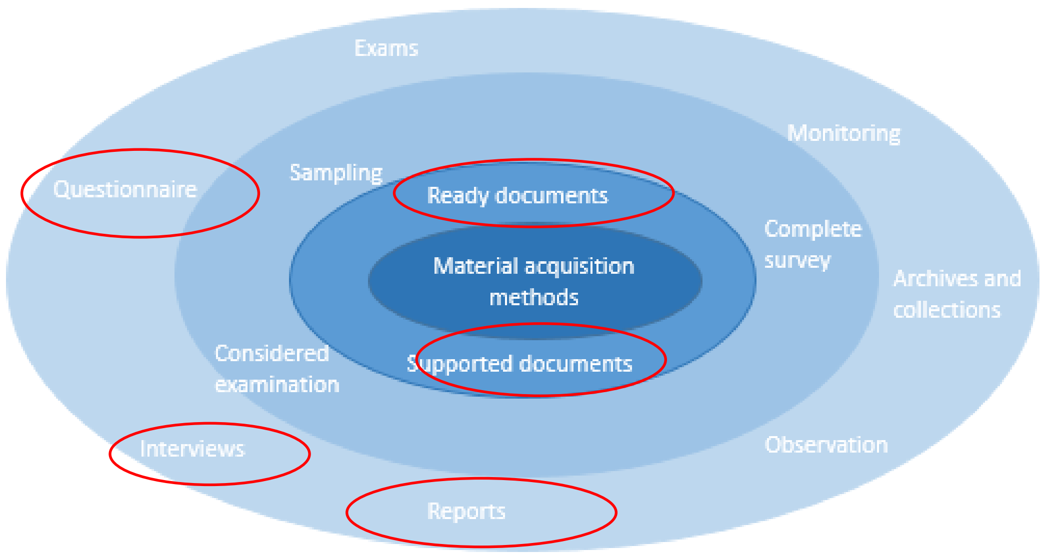

FIGURE 14. Material acquisition methods used in this research. (Jyväskylän yliopisto, tutkimus strategiat, 2016.)

Material used for research can be very diverse and due to that there are also different material acquisition methods. Composition of the research affects the material acquisition method selection. It defines a way how the material will be processed and analysed. Certain type of material is applicable for certain problem deployment and they need certain research methods. With material acquisitions methods both extensive and compact schematic choices can be construed. These different levels are described in the picture with locating methods either near or far from the central point. (Jyväskylän yliopisto, aineistonhankintamenetelmät 2016.)

These material acquisition methods can be used to gather material sets. Example of ready material sets are materials gathered from research project or results from some authorities' actions. Also, different organisations and institutions are collecting material sets that can be used. For specific material sets, there are special concepts. What is worth to note is that this sort of collections might allow only one kind of problem deployment or analytical method. (Jyväskylän yliopisto, aineistonhankintamenetelmät 2016.)

5.4 Survey

Survey is a research strategy which is used to collect information and data with questionnaire and interview methods from a large amount of selected investigation targets. There are two principal ways of survey research which are questionnaires and sampling. Questionnaire have predefined questions used to collect information from target group / individuals. In sampling, there is selected subgroup of individuals to answer the questionnaire and collected information can be concluded to entire population of interest. (Research connections 2017.)

Basic idea of interview is that the interviewed target will freely tell and discuss about the matter compared to questionnaire sheet. There is possibility to use one´s own terms and expressions while answering to the questions. Basic forms of the interview are questionnaire sheet, open and deep interview, and also, theme and half structured interview which are in between. This can be compared to open-ended questions. (Research connections 2017.)

At a starting point of a research, there are specific phenomena’s, properties or commonality of phenomena’s, appearance, intervention or investigation of divergence. Results of research should be generalised from the sample to the complete universe. Survey as a research method, includes a lot of different problem setting possibilities, and it can be performed with different analytical methods. Starting point of survey-research can be thought to be in quantitative research. Depending on the survey and interview methods, a questionnaire material can still be analysed either qualitative or quantitative methods. (Jyväskylän yliopisto, Survey 2016.)

Questions which have been used in the interviews at the first round, have been prepared based on the existing experience and the supporting business cases presented in the chapter 6. The business cases used are selected because they give a support for relevant matters. These matters are mind-set change, product safety requirements clarification and awareness raising. Lessons learned from the cases can be used to improve way of working in the different market areas. In addition, the information has been used in this research.

Questions for the second round have been prepared based on the technology review whereas ready-, supported documents and reports where used along with the 1st round questions and answers.

Transcription is one method to open up the interview, and it can be done with different ways from precise manner to a referring transcription, in the latter, the interview can be simple, for example only bullet points. Factors which affect to the method used are time schedule, effectiveness, communication and ability to read. Very detailed transcription can miss the point, when too raw can miss relevant points. (Nikander 2010, 432-435.)

Quality of the transcription depends a lot on research worker skills to capture emotions and situations of the interview. Also, the final text formed from the transcription is dependent of writer's judgement for the matters what and how will be written to the research work. (Nikander 2010, 432-435.)

A lot of different methods of transcription have been introduced in digitalisation era like video compared to past. For example, video recordings compared to only voice recordings. The way how the transcription has been carried out informs theoretical understanding of the researcher regarding the research subject. (Nikander 2010, 432-435.)

Most of the interviews have been written out as notes from the discussions. The interview which was related to the product liability law, has been transcript in a precise manner due complexity of the subject. Part of the responses from questionnaires are as e-mail discussions. (Tietoarkisto 2017.)

5.5 Business Cases

Case study is a research method, which purpose is to investigate in a detailed level only one or few phenomena's, or entity of phenomena. Case study compared to research study is not so tightly determined and it can be used with many different analytical methods. (Jyväskylän yliopisto, Tapaustutkimus 2016.)

Investigated cases can be diverse. Often this case is anyhow understood as limited individual entity or unit. In case study, the aim is to produce detailed and intensive information from the selected case. Case study is not trying to reach generalised information using similar methods like survey, but it tries to understand and interpret in detail those single cases with their specific context. It collects information related to the dynamics, mechanisms, processes and internal guidelines in a way that with the results can be shown more extensive socio cultural meaning and some kind of generalisation or mobilisation. (Jyväskylän yliopisto, Tapaustutkimus 2016.)

The business cases used were selected because they support the theme of the research. For example, one of the business cases is describing the mind set change within the organisation and lessons learned from this supports this research how the customer mind set could be similarly changed. Business cases have been presented in chapter 6. (Jyväskylän yliopisto, Tapaustutkimus 2016.)

6 BUSINESS CASES

In the following chapters few business cases have been introduced. The aim is to improve and raise safety awareness, and try to change mind-set from gas turbines to reciprocating engine power plants, and improve competitiveness while being involved for the customer sales meetings. Related questions for chapters 6.2, 8.1 and 8.2 are presented in Appendixes A and B.

Business case 6.1 discuss about the attitude and mind-set change within and between the organisations. Case 6.2 is about the importance of investigating and clarifying the requirements related to product safety. Finally, case 6.3 discusses about the lobbying and its purpose to achieve acceptability to provide a power plant project.

6.1 Attitude change between organisations

This business case concerns the attitude change between the organisations towards the product safety and safety mind-set in general level. Reason this has been selected was that it needs more than one to make the change happen and complete understanding for the matter which is driven. This specific case have taken long time to clarify the situation for all involved and to turn them as ambassadors of the concerning subject in order to have management and organisation support for the work.

Networking in internal and external organisations is important in order to embed the product safety requirements in design. When there is critical amount of safety oriented persons in the organisation the change will happen by itself.

Easiest way to justify something is to build a business case behind the matter. This would consist of actual projects where the similar requirements have been presented and what will be the future prediction. Sometimes there can be things which are just a disappearing trend or on the opposite, legislative guidance or requirement. Survey for these kind of things is essential to map overall effect. After the requirements are found and common understanding has been achieved, preparation for the actual promoting can start.

The facts and requirements from previous projects were collected. Pro’s & cons along the cost benefit calculations were listed to justify requirement for the engineering responsible organisation.

At this stage it can be seen that it is easier to justify e.g. product change request due safety requirement for a smaller group of people than a fifteen to twenty people at once. One essential requirement is to get people understand the need and benefit what is achieved. The safety culture change has started and a lot of smaller meetings have been held. There have been persons from different field of expertise and organisation level. When they have discovered the benefits of process/product safety risk assessments separately and has not been vulnerable to colleague opinion, they have accepted the presented matter and adapted the information also to their daily work.

When people that have already changed their mind-set are put together again to decide the Wärtsilä solution the safety aspects shall be taken into account unanimously and they thoroughly understand the need of change.

6.2 Importance of the product safety requirements clarification

This specific business case concerns the importance of product safety requirements clarification in early phase of any task of company, in this case especially project development and project delivery. This has been taken as case because investigation of the product safety requirements from both legislative and customer point of view may and can prohibit to deliver the end product in so it would comply with the safety requirements. It can also cause a considerable time delay or design changes to product or project execution which can be very costly in terms of contract value. It may also tell that is it even reasonable to execute the project in first place.

Product safety related matters are always one part of the technical requirements of the power plants or any other significant industry investment. But many times it will depend on the customer and customers industry how important and demanding safety requirements will be applied for the project. Sometimes there will only be few very basic risk assessment that are done. However there is variation in the requirements for safety analysis and which phase of the project they are done.

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Worth to note is, like in this case that the requirements for product safety presented can be such that power plant suppliers have to follow the specified requirements to be compliant to deliver the project. To avoid this kind of problem, there can be qualification where you need to show capabilities to comply with the safety requirements.

When the product safety requirements are not clarified in the sales phase it will in worst case create significant project risk both from the safety and cost point-of-view. Depending on the location of power plant, the most significant risk is the impact for surrounding environment in case of accident, both for nature and possible local inhabitants. Cost impact of the studies itself is not remarkable in terms of overall costs. The biggest problem is non- identified design changes in early phase, which the safety studies will identify. In worst case scenario, when the safety studies and overall safety is not implemented for the power plant, there is possibility for Major Hazard Accident causing huge costs, loss of reputation and penalties neglecting the safety. Reputation of all involved parties will suffer, even more today since public opinion is for the safety.

In this case, the importance of the reliability of power production was essential. To ensure reliable and continuous energy for the consumers, it is essential to do thorough risk assessments for the power plant. Requirement in relation to product safety was presented well upfront the project but not fully understood in the sales phase which was the case also with other power plant providers including gas turbines.

6.3 Lobbying

The lobbying business case was selected since it is partially related to industry mind-set change discussed in this research. Good understanding of the subject is essential to have a successful result of promoting. In this case, project and sales teams were prepared with the information related to product safety, what it is and how it is done and achieved in Wärtsilä. Similar kind of task would be needed in wider extent to raise awareness of safe design and way of working principles within the organisations, and later, for the concerning external parties and customers.

Raising awareness plays an important part to increase sales and company products profile. There has been one recent case that project permission to proceed has delayed because of competitor's similar type of gas fuelled reciprocating engine power plant incident which luckily caused only minor consequences.

After the incident, there was need for a community meeting where the purpose was to tell for inhabitants and ensure them about how safe Wärtsilä gas fuelled reciprocating engine power plants are.

Presentation material was created to show different safety analysis, procedures and other related matters done for the gas power plant solution in different design phases and during overall lifetime. Feedback from the presenters was that they had a good overall presentation material and they managed to ensure community people of Wärtsilä power plant technology.

With the different risk analyses, it can be shown why something is designed and safety measures connected to that design. For example, in the Japan energy markets, power plants applications and the reciprocating engines are not allowed for some reason to use rupture discs in the exhaust stack and one of Wärtsilä's competitors is not using them. If it can be clearly seen and shown both with risk assessments and experience from industry that rupture discs are not needed, their existence can be questioned.

However, Wärtsilä, based on their own risk matrix, has not found rupture disc free design advisable. In this type of scenarios, awareness of customer can and need to be raised about the product safety to justify design solutions. Having understanding of risk assessments and purpose of them, -design solutions done can be seen as enablers for safe and reliable plant operation to minimise cost of end–user's in case of hazardous scenario. History have shown in many industries that there is no fully awareness of the risk assessments, risk matrix or acceptable risk levels, but these have been, for example, calibrated wrongly allowing false information as input for the design because the evaluation does not match with its purpose.

Hazardous scenarios can never be fully mitigated but the frequency of the scenario can be reduced. That does not change guarantee the fact that hazardous scenarios are still possible to happen tomorrow, similar to a meteor strike. It will be the end-users responsibility to define what their acceptable risk criteria are, and to define as low as reasonable (ALARP) limits for the risk mitigation.

7 INTERVIEW

In this research, various experts have been interviewed around the organisations from sales to technical experts. Interviewees had experience on both gas turbine and reciprocating engines configured power plants. The interviewees have been working in different countries, but especially persons working in U.S. were seek to be interviewed in order to include as much customer feedback as possible to various topics.

Persons who were interviewed were in following positions within in Wärtsilä;
Directors (various positions including sales, marketing and project management)
Legal counsel
Business development managers
Market development managers
Sales managers and engineers
Project managers and engineers
Sales area manager
Proposal managers

Also, open discussions outside of Wärtsilä were discussed with few persons located in Finnish international companies working with product safety matters. Part of the same interview questions (Appendix A) were used for these discussions. As a result, similar kind of experiences were shared from various matters that has been raised in this research.

Selection of interviewed persons within Wärtsilä was based on the results of discussion with various directors and managers who have both extensive network and experience within company. To clarify the research and need of persons for interview, nearly the same questions were used as basis to have clear understanding of research intent.

7.1 Customer related matters

Based on the interviews, it is evident that product safety is not prioritised over other matters. Main questions are often related to emissions, NERC - new standards for criticality ratings, efficiency, cleanness of engines/plants, power output, derating on altitude and temperature. There are rarely discussion about different risk assessments or reliability / availability of power plant, which are almost hand-to-hand related with each other.

It depends also a lot of customer that how much product safety related information is discussed and requested. Among the following group of power producers, the Oil and Gas, Municipalities, or Independent Power Producers (IPP's), the Oil and Gas segment is the most demanding especially in terms of product safety. Oil and Gas segment has developed in safety culture during the years mainly due to major accidents happened in the oil and gas plants. The safety culture is implemented through organisation and these customers know what solutions they want and what they do not want.

The customers who have traditionally been using gas turbine power plants, are not aware of the reciprocating engine power plants and are not familiar either with their requirements. Similarly, engineering companies are not aware of the requirements in general or especially regarding safety. This concerns especially full Engineering, procurement, and construction (EPC) -contractors in the reciprocating engine power plant segment.

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Customers have challenges to understand the technology and performance of the reciprocating engines power plants. Risks are considered much higher and solution more unreliable than they actually are. Redundant engines are requested similar to gas turbine configuration. The flexibility of multi engine solution is unknown. Especially, the understanding that the engines can run part load and still be efficient. The customer needs to be educated of the specific features of reciprocating engine power plant. It is important to educate the customer in order to optimise the plant configuration while taking into account the maintenance costs- the more components the higher the maintenance cost.

7.2 Wärtsilä related matters

Wärtsilä´s approach towards the customer has been to prioritise the economical and performance related matters in sales negotiations. Safety risks mitigating has not been the cornerstone of the sales strategy. Reference projects has been presented and an unofficial tour to Wärtsilä power plant arranged to show in practise how the safety has been considered. This way the specific information Wärtsilä has already developed to product safety, is not presented during sales phase.

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Cost impact of product safety is not discussed in a detailed level in sales phase. The impact will come during the project phase when it may have significant impact for the overall cost to have safe design solution.

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Improvement should be done in communication between the different disciplines of the organisation and product safety team to ensure that safety requirements are clarified in the beginning of all the projects. Product safety team should be involved to the discussions with customer or their representatives in the sales phase. Especially, would be important to have straight discussion with customer´s product safety expert to be in line with customer´s view of product safety. This would eliminate the possibility of unrealistic or irrelevant requirements from the contract.

7.3 Product liability law

Investigation for the product liability was done similarly to other research matters. Interview questions were created based on the background check and supported by the earlier discussions. Interviews raised a lot of important matters that should be considered for further investigation.

It was clarified that product liability is state specific and determined by them. If there is governing law from federal government, it rules over the state's law, but currently for product liability the procedure is not the same. There is though same pattern in most of the states, in which are gone through the things you need to show to proof for a product liability claim. Similarly, same defences are available. This can give a small prediction what need to be make sure to cover, for example duty to warn and duty to care. This means that states have also the right to decide what standards you need to follow to fulfil the requirements, in this case for power plants.

For product liability, there seems to be a pretty uniform set of rules across the different states of U.S. Due this, it is fairly familiar to what you would have to show to proof that there was damage because of product liability claim, and what product manufacturer would have to show as defence against something like that. In case, if manufacturer puts a defective product in hands of consumer, manufacturer could have claims against you brought from design issues, manufacturing issues or marketing defects. With marketing defects, it is meant that manufacturer did a failure to warn about the danger of product. There are lots of other ways to come at under negligence, strict liability, due to warranty, and consumer protection claims, for example, to get a product issue.

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From customer point of view, in case of accident they would have to show and prove that there was an injury, or laws that the defective product did not comply with and it was what cause the injury or loss, not just that there was a damage. Respectively, a manufacturer would have to pay attention to a duty to warn. This would in practise mean, information how to properly use the product, maintain it or using original parts. From technical aspects, it needs to be informed the right operation manuals and so on. If there is a danger that manufacturer is aware of, it needs to be informed to customer and then the product meets the duty to warn. If the customer stops following or listening the guidelines and information from manufacturer, it is then negligence and can be shown that failure was partly or entirely customer fault.

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7.4 Limitations

There were multiple limitations for the research work which have had impact to the result. However, they give also feedback what should be highlighted in the way of working. One common connecting factor was the thorough understanding of product safety.

Depending on the interviewed person's background, the responses needed further clarification what was meant. Person who had process industry background, was aware how product safety consists of multiple matters which need discussion with customer and internal disciplines to reach best end result in power plant design, or whatever is the project delivery or product. This may have impact on overall competitiveness and company performance with customers while the customer is not satisfied with the way of working and overall design due missing product safety procedures, missing risk assessments or because of other related matters. At the end, customer may not come back to use company services. An extreme example for this kind of case is the IKEA lawsuit where dressers were fallen for few children's causing fatalities because their instructions missed the safety warnings (Acker, 2015). Due this, high penalties were paid and considerable number of dressers were withdrawn from markets to avoid further liquidated damages for company (Wolf, 2016).

Regarding the research work itself, it can be seen that broader number of interviews would have given better results. There were limitations to involve more persons internally since it is difficult to find persons who are aware of product safety and who would have been involved with customer discussions. It is also cultural thing to get people for interview. Better results would have been received and more interviewed persons would have been available for discussion if this would have been held locally in U.S. Part of the U.S. culture is to have face to face discussions, especially when first contact is created.

Also, the legislation structure in U.S. is very complex and much more time would be needed to investigate in detail the differences between the states which were not reasonable to execute within terms of this research.

7.5 Summary of interviews

As a result from the interviews, there was a common perspective that the product safety is not the key matter discussed in marketing or sales phase. Everyone had common understanding that the product safety is important matter that should be discussed more in sales phase and in U.S. market area. Some of the persons also mentioned that the product safety should be internally more informed.

From customer side, can be highlighted that there are gap between the knowledge of reciprocating engines and gas turbines. This was said by almost every person interviewed. Too much of information and requirements are generalised from gas turbines to reciprocating engines even though the concept and severity of reciprocating engines are smaller.

Important matter raised from the interviews, was product liability law. It is very wide matter since it can vary between the states, and it is critical in a way it determines the requirements for many matters. Also, responsibility of manufactured product was raised: it cannot be removed with any contractual terms. Due this, it has been raised also in the improvement section and should be highlighted for future improvement cases.

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8 IMPROVEMENT SUGGESTIONS

Results from the research were compared to the literature and the overall background review done.

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8.1 Mind-set change

Mind-set change is one of the top items that should be done to get people understand different impacts of product safety. It should be understood, that product safety in the U.S. markets is the last item you should exclude from project costs, resources or from anything else.

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Literature mentions the importance of leadership to different organisational cultures and the commitment of top management to lead the way of working in to lower level of organisations. If the top management is not leading through safety or putting the effort for the key areas, the safety culture is not changed. They should openly take actions and inform from lessons learned if such exists, and locate and allocate necessary funds for the training and product development where needed.

8.2 Key performance indicators for the product safety performance

Currently, there are two high level key performance indicators used in Wärtsilä for product safety so the visibility and progress is not so clear. These are the amount of risk assessments performed for the delivered projects and share of risk assessments done for development projects. KPI's can be determined more detailed level based on the company and organisation needs, and to give feedback both internally and for customers as sales argument.

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8.3 Competence management

Development of the competence management system concerning product safety. Examples of such activities are;

- How to measure competence, justify person allocation for the tasks
- Improve overall awareness in the product safety
- Suppliers' competence management

This would ensure that everyone who is involved for the certain lifecycle phase of the power plant, has needed competence for subject from very general level to expertise level depending on the position and tasks. There are many things which would need to be covered and this should company's own investigation and development task.

8.4 Product liability law

More effort should be put for the investigation and resources for product safety management in the U.S market area. Following single items have raised up during this research, and what should be improved in various levels in the company to improve overall performance;

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9 CONCLUSIONS

This research is describing reciprocating engine based power plants in U.S. energy markets and how the competitiveness could be improved with the means of product safety. Also, it was investigated what the technology risk is between the gas turbines from customer point of view and how it could be affected with product safety means. Product safety as a part of company way of working can be assumed to have effect to competitiveness.

The aim of the research was to investigate if the product safety could improve the competitiveness and reduces the technology risk in eyes of U.S. customers who are used to use gas turbines in history of energy markets. Literature review was done for variety of related subjects within energy industry to have common understanding of both technologies and how product safety is visible in these. Business cases were selected to support the research question. Together with the literature review and business cases, interview questions were derived and survey was performed with interviewing variety of persons within Wärtsilä.

Based on the interviews, the technology risk is mainly related to the unfamiliarity of the reciprocating engine technology, maintenance costs due equipment amounts and plant reliability. Product safety matters, risk analyses, safety management and so forth, are not seen as the actual technology risk matters power plant customers would highlight.

Many times, reliability and availability are not seen as part of product safety even though they are. More often, safety may be seen as limiting factor, which is not true and it shall always be based on the end users risk acceptance criterion. Risk management and its related tasks are an evidence of safe and reliable end-product, and justification of good design.

With product safety, technology risk mitigation can be affected in a way to do certain reliability and availability analyses, for example, fault tree analysis. Other risk assessments can make the design better in terms of simplifying the process, minimising unnecessary equipment and removing the design errors which might cause process upsets in operation phase affecting, for example, for reliability.

Reliability of this research and results are working more as input to Wärtsilä for further investigation and development actions. Sampling of this research was not large, only 30 persons, which does not represent large scale reliability. In addition, there are interviewees own interpretation of industry and customers. These persons were selected from experience: who have extensive experience from industry and customers in the segment, and who have worked closely with the customers. Better results could have been received if the customers would have been interviewed as part of research, but this would have been difficult to arrange in this extent of research. As further development, it is recommended to have discussions with customers.

Limiting factors for the research were in general the awareness of the product safety, which also in some extent limited the selection of interviewed persons, cultural matters how to get in to discussions and of course the time frame of this work. There are not so many persons who have knowledge of product safety to have detailed discussions. Regarding the research, better results could have been received if the persons located in U.S. would have been interviewed locally. First contact with the persons commonly is made face to face, not via video meeting.

Internally, this research gives a lot of information to improve organisations way of working and what areas need to be further investigated, whereas one major area is, for example, the product liability between the states. Other areas for further investigation and development relates to general clarification of U.S. market area to have common understanding of states differences in standards and legislative compliance. Also, the competence management should be investigated how it would be reasonable to execute and in what extent. This was anyhow related both internal, and in some extent for customers and engineering companies.

Despite the fact that this research did not give the exact answer and result for the research question what was planned to be achieved, this research raised various matters that would need to be improved within the company. For example, because there were some internal persons responsible for critical tasks in customer interface, mind-set change would need manager in higher level who is capable in change management. It is clearly visible that the product safety is now in transition phase within the company as well as in customer interface and market – product safety is recognised as important factor but it is not widely adopted.

At the end, this research work was larger than expected which means that there are many findings requiring further investigation in the future. Major matter which had impact was the individuality of the states in between the requirements and product liability. Product safety can be in some extent thought in general level but it would need to dig in to the details of concerning state to have exact information what the legislation states for product liability for example. Other subjects that would need further investigation would be key performance indicators for product safety to respond more in detailed matters.

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APPENDIX A: INTERVIEW QUESTIONS

In the first round the presented questions were following;

- What kind of information customers are requesting or discussing with you in respect to product safety related matters.
- Customers have this technology risk mind-set regarding reciprocating engine power plants, what kind of things they are considering as risk factors.
- Are they asking about safety studies what are done for design, are they asking about process safety related things or similar?
- Is there product safety / safety responsible persons from customer side involved for discussion and how this is handled?
- What are the safety requirements and how these are required, on what basis?
- Is there mentioned about product safety management?
- How does competitors represent their product safety for customers?
- Is there any comments how they have designed products safe or any mentioning is there safety studies carried out?

For the second round the questions were following,

- Is there difference per customer what are the focus points (safety, reliability, costs, efficiency et cetera.), normally it is seen / spoken that O&G customers are safety oriented?
- Why we are not discussing about product safety and its benefits?
- Do the customers set same product safety requirements for gas turbine / combined-cycle plants manufacturers in sales phase, risk assessments et cetera.?

APPENDIX B: BUSINESS CASE QUESTIONS

- How and from where the product safety requirements came from? From offshore or some other basis?
- Were these product safety related questions noticed, discussed and understood in the sales phase or did these come upfront in the project?
- Were there other competitors in the sales phase, is it known that did they understood the requirements how demanding project this would be from safety point of view?
- Where we the only one who accepted the product safety requirements?
- Did competitors present their capabilities for product safety matters?
- Was there gas turbines as option for this project, why did we won this project (not only by cost if that is possible to exclude)?
- Reliability was one of the criteria's for operation, was product safety / risk analysis /risk management discussed in this matter?
- Did the customers set same product safety requirements for gas turbine / combined-cycle plants manufacturers in sales phase, risk assessments et cetera.?

APPENDIX C: LIST OF STANDARDS

Standard Code	Standard Name	Gas turbine power plant	Reciprocating engine power plant
IEEE	The Institute of Electrical and Electronics Engineers (Multiple standards)	X	X
NEC	National Electrical Code (Multiple standards)	X	X
ASME	American Society of Mechanical Engineering (Multiple standards)	X	X
Machinery directive	The Directive 2006/42/EC of the European Parliament	X	X
ANSI EN ISO 12100 / ANSI B11.0	Safety of machinery - General principles for design -- Risk assessment and risk reduction	X	X
IEC 61508/61511	Functional safety of electrical/electronic/programmable electronic safety-related systems	X	X
VGB R 108	Fire protection in the power plant	X	
VGB R121M	Technical guideline for monitoring, safety and protection equipment for gas turbine installations	X	N/A
VGB 121 M GT	Guideline for supervision-, limiting- and protection devices on GT-systems	X	N/A
TRD 411 / 412	Technical rules for gas/steam generators	X	N/A
EN 50156	Electrical equipment for furnaces	X	N/A
ISO 7919	Mechanical vibration of non-reciprocating machines – Measurements on rotating shafts and evaluation criteria	X	N/A
ISO 10816	Mechanical vibration – Evaluation of machine vibration by measurements on nonrotating parts	X	N/A
IEC 60079	Electrical apparatus for explosive gas atmospheres, Part 29-2 Gas detectors	X	

ISO 21789	Gas turbine applications - Safety	X	N/A
API RP 500/505	Recommended practice for classification of locations for electrical installations at petroleum facilities	X	
IEC 60079	Electrical apparatus for explosive gas atmospheres, Part 10: Classification of hazardous areas, Part 11: Electrical apparatus for explosive gas atmospheres, Part 14: Electrical installations in hazardous areas (other than mines), Part 15: Construction, test and marking of type of protection "n" electrical apparatus	X	X
IP part 15	Area classification code for petroleum installations	X	
EN 50272-2	Safety requirements for secondary batteries and battery installations – Part 2	X	
VGB-R165	Recommendations for the improvement of H2 safety in hydrogen-cooled generators	X	
IEC 60034-3	Rotating electrical machines – Part 3: Specific requirements for cylindrical rotor synchronous machines	X	
IEC 60204-1	Safety of machinery – Electrical equipment of machines – Part 1: General	X	X
IEC 61140	Protection against electric shock - Common aspects for installation and equipment	X	X
DIN EN 50274	Low-voltage switchgear and control gear assemblies – Protection against electric shock	X	
EN 50272-2	Safety requirements for secondary batteries and battery installation – Part 2: Stationary batteries	X	
IEC 62305	Protection against lightning	X	X
IEC 60255	Measuring relays and protection equipment	X	
NFPA 37	Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines	X	X

NFPA 850	Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations	X	X
IM/24	Guidance Notes on the Installation of Industrial Gas Turbines, Associated Gas Compressors and Supplementary Firing Burners	X	
NFPA 56	NFPA 56 (PS), Fire and Explosion Prevention During Cleaning and Purging of Flammable Gas Piping Systems	X	
ANSI/AIHA Z10-2005	Occupational Health and Safety Management Systems		
NFPA 54, ANSI Z223.1	National Fuel Gas Code		