CHALMERS

Operational advantages and limitations of battery hybrid operations

Bachelor thesis in Marine Engineering

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SAMMANFATTNING

Denna studie avhandlar hur maskinbefälen ombord på en RoPax fartyg uppfattar de operativa förändringarna som har uppkommit under den dagliga driften efter implementering av litiumjonbatterier för batterihybriddrift ombord. Studien redovisar de fördelar och nackdelar som upplevdes av maskinbefälen till följd av konverteringen samt dess inverkan på säkerhetsorganisationen ombord. Studien genomfördes genom att intervjua maskinbefäl ombord på ett svenskt RoPax fartyg. Det insamlade materialet analyserades sedan kvalitativt för att besvara studiens forskningsfrågor. Dataanalysen påvisade att alla tillfrågade maskinbefäl hade en positiv syn på konverteringens inverkan på deras yrkesroll. Konverteringens främsta fördelar ansågs vara förmågan att förebygga strömavbrott, så kallade ”blackout”, längre intervaller mellan underhållet samt minskad bränsleförbrukning. Eventuella nackdelar med installationen bedömdes vara risker med en eventuell batteribrand samt att delar av systemet uppfattades som väldigt avancerade. Säkerhetsorganisationen har genomgått utbildning för att få kunskap om hur man agerar vid en potentiell batteribrand.

Nyckelord: Batterihybriddrift; Sjöfart; Litiumjonbatteri; RoPax, Teknik

ABSTRACT

This study deals with how engineering officers onboard a RoPax vessel perceive the operational changes that have occurred during daily operations after the implementation of lithium-ion batteries for battery hybrid auxiliary propulsion onboard. The study deals with the advantages and disadvantages experienced by the engineering officers both as a result of the conversion, as well as its impact on the emergency organization on board. The study was conducted by interviewing engineers working in the engine department onboard a Swedish RoPax vessel. The gathered data was then qualitatively analysed to answer the study's research questions. The data analysis showed that all surveyed engine officers had a positive view on how the conversion had affected them in their line of work. The main advantages of the conversion were considered to be the ability to prevent power outages, so-called "blackouts", longer intervals between maintenance and reduced fuel consumption. Possible disadvantages of the installation were the risks posed by a possible battery fire and that parts of the system were perceived as very advanced. The emergency organization underwent training on how to act in the event of a potential battery fire.

Keywords: Battery hybrid propulsion; Shipping; Lithium-ion battery; RoPax; Technology

NOMENCLATURE

AMOS	Asset Management Operating System
Blackout	Loss of electrical power onboard
BMS	Battery Management System
CCTV	Closed Circuit Television
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
ESS	Energy Storage System
HAZID	Hazard Identification
IACS	International Association of Classification Societies
IMO	International Maritime Organization
ISM Code	International Safety Management Code
LIB	Lithium-Ion Battery
MARPOL	International Convention for the Prevention of Pollution from Ships
MEPC	Marine Environmental Protection Committee
Peaks Shaving	Leveling out electrical consumption peaks with stored energy
PMS	Power Management System
RoPax	Roll-on/Roll-off vessel with vehicle and passenger carrying capabilities
R&D Project	Research and Development Project
SECA	Sulphur Emission Control Area
SOLAS	Safety Of Life At Sea
STCW	Standards of Training, Certification and Watchkeeping
Thermal runaway	Process which is accelerated by increased temperature that in turn releases more energy that further increases temperature
UPS	Uninterruptable Power Supply

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1 Introduction

The availability of reliable energy has always been a crucial factor in the global shipping industry. While shipping was in its cradle mariners relied on manpower and wind power to propel their vessels across the oceans. The development of steam engines and later combustion engines made the mariner dependent on fossil fuels to provide the energy necessary for propulsion. With an ever-changing transport market, shipping companies are forced to adapt their business model to stay relevant and ahead of the competition.

In recent years the environmental aspect of the transport industry has come in to focus, this in turn has spurred the industry develop and apply new technologies. The International Maritime Organization (IMO) states that emissions from shipping could rise between 50 percent to 250 percent because of increased demand for maritime transports (International Maritime Organisation, 2020).

In an effort to combat the increase in global shipping emissions IMO has increasingly tightened its regulations concerning air pollutions by updating and amending the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI. According to International Maritime Organization [IMO], (2020i) the application of what is called “IMO 2020” has led to a significant reduction in allowed Sulphur Oxide (SO_x) emissions outside the designated Sulphur Emission Control Areas (SECAs). To even further reduce emissions from shipping the IMO has also developed more stringent regulations concerning Natrium Oxide (NO_x) emissions, that the shipping industry in the North and Baltic sea Emission Control Areas (ECA) will have to comply with from January 1 2021 (International Maritime Organization [IMO], 2020j).

Energy Efficiency Design Index (EEDI), a measurement on how much CO_2 a vessel produced per tonne of cargo per mile (Geertsma, Negenborn, Visser, Hopman, 2017). These regulations mean that new ships built in 2030 shall have a 30 percent lower EEDI than ships ordered before 2013 (Tzannatos & Stournaras, 2015).

Local authorities in Sweden have adopted a new long-term climate objective that convey that Sweden by 2045 shall eliminate net emissions of greenhouse gases (Regeringskansliet, 2017). This corelates in that emissions from transport, industry and agriculture among others needs to be reduced by 63 percent compared to levels achieved in 1990 before 2030.

In order to stay relevant, the shipping industry has been spurred to invest in alternatives fuels. Some shipping companies have adopted LNG as fuel on their vessels to reduce emissions, but this alone is not sufficient to reach the climate goals. To maximize the benefits of these new fuel alternatives the maritime industry will profit from combining these with battery hybrid solutions. Battery hybridization implies that the ship can store energy onboard to be used either for propulsion or to handle peak demands. Peak demand is a term used when excessive amount of power is needed for a short period for example when a vessel is manoeuvring, or heavy deck machinery is used. This will enable the ship to utilize fewer generators for redundancy and enable the remaining generators to operate more efficiently (Hägg et al. 2018: Geertsma et al. 2017).

While there are multiple ways to store energy, lithium-ion batteries are typically used for these applications because they are more energy dense then competing energy storage technologies. Development has in recent years produced lithium-ion batteries that can be charged faster and retain more energy making them a more attractive investment according to Hägg et al. (2018). With the introduction of new technologies comes new challenges for the engineers responsible with maintaining and operating the vessel. This thesis will examine how the application of these new system affects the operation of a merchant navy vessel.

1.1 Purpose

The purpose of this study is to investigate battery hybrid auxiliary propulsion from an operational standpoint as experienced by engineering officers. The study will illuminate the pros and cons of operating a RoPax vessel utilizing battery hybrid auxiliary system.

1.2 Research questions

- What are the primary benefits of operating with a battery hybrid auxiliary system onboard from an engineer’s perspective?
- What are the primary disadvantages of operating with a battery hybrid auxiliary system onboard from an engineer's perspective?
- Did the application of the battery hybrid auxiliary system affect the emergency organization onboard?

1.3 Delimitations

The study is limited to commercial RoPax vessel operating in Scandinavia, that has installed a lithium-ion battery pack to fill the role of an auxiliary engine. The study is focused on the marine engineers and the electrical officers onboard. The study will be evaluating one vessel working on a predetermined route.

2 Background and Theory

The following chapter aims to introduce relevant information needed to analyse the data produced during the interviews. This chapter will encompass theory on RoPax vessels, general engine arrangement, power grid and introduce the lithium-ion battery. Relevant legislations will be highlighted and lastly, the target vessel and the process of how it was converted will be introduced.

2.1 RoPax

A definition from Marine insight (Kantharia, 2019a) states that *"ROPAX is an acronym for roll on/roll of a passenger"*. RoPax vessels similar to the vessel illustrated in Figure 1 are a part of the roll-on/roll-off (RORO) family but differentiates from a RORO vessel by its capacity to carry and accommodate passengers as well as wheeled cargo (Kantharia, 2019a).

Figure 1. Typical RoPax vessel (Authors own copyright)

A passenger carrier is a vessel intended to carry more than 12 passengers onboard. Passenger carriers are categorized as either a cruise ship or a ferry able to carry passengers and cars (Passagerarfartyg, 2020; Transportstyrelsen, 2008). When a RoPax exceeds a capacity for more than 500 passengers it is often called a cruise ferry (Kantharia, 2019a).

RoPax vessels are not to be confused with cruise ships or ferries. Cruise ships are often large vessels that are descended from transatlantic ocean liners. Modern cruise ships are purpose-built to function as large floating hotels and entertainment centers. They usually incorporate high superstructures that enable them to accommodate a large number of guests as well as a big crew complement. Because comfort is one of the key aspects while on a cruise, these vessels are usually designed with noise, vibration reduction and stability in mind. Cruise ships generally don't have a need to travel at high speeds but instead have a high demand for systems involved in passenger comfort. To accommodate for these criteria cruise ships often employ multiple medium speed trunk engines that produce electricity that is utilized both for propulsion and for the vessel's electrical needs (Types of ships, 2020).

Ferries on the other hand can be built in any size and are intended to carry passengers over short water passages where building a bridge or tunnel is impractical according to Encyclopedia Britannica Online (Types of ships, 2020). They are often arranged to be able to carry vehicles, and traffic fixed routes. Loading the vehicles is often accomplished by either side doors or by means of bow and stern ramps similar to RoPax vessels (Types of ships, 2020).

2.2 Regulations

International legislations govern how the shipping industry should operate to ensure the safety for people and the environment in addition to also upholding a framework to ensure a fair shipping industry. Regulations are often created as a result of major accidents that have occurred over the years and regulate how the vessels are constructed, manned and operated.

2.2.1 International Maritime Organization

The International Maritime Organization (IMO) is a specialized agency of the United Nations (UN). Its purpose is to create and uphold a legal framework for the shipping industry that is "universally adopted and universally implemented" (International Maritime Organization [IMO], 2020a). IMO regulate the shipping industry through international conventions that when entered into force are binding for all member states.

2.2.1.1 SOLAS

The International Convention for the Safety of Life at Sea (SOLAS) is often regarded as the most influential convention in regard to merchant vessel safety. It was adopted in 1914 as a reaction to the sinking of the Titanic. Since its adoption it has existed in multiple forms, the latest being the 1974 version. This has been amended continually and is often referred to as SOLAS 1974, as amended (International Maritime Organization, 2020b).

The purpose of SOLAS is to ensure that the shipping industry has minimum requirements to follow regarding how vessels are constructed, equipped and operated (IMO, 2020a).

Chapter 1 regulation 6 states that it is the flag states responsibility to ensure that current regulations are followed onboard its vessels. This can be done either by the flag states own inspectors or entrusted to "surveyors nominated for the purpose or to organizations recognized by it" (International Maritime Organization [IMO], 2014). The publication currently being used is SOLAS Consolidate Edition, 2014 (International Maritime Organization [IMO], 2020c).

2.2.1.2 MARPOL

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the principal convention dealing with pollution that occurs accidentally or during operations. Following a series of tanker accidents in the 1970´s the convention that was yet to be adopted was incorporated in to the 1978 MARPOL protocol. The combined document was finally entered in to force in 1983 and has since then been expanded with several annexes (International Maritime Organization [IMO], 2020d).

MARPOL includes regulations regarding the prevention of pollution by oil, harmful substances, sewage, garbage and air pollution among others. The current version is MARPOL, Consolidated Edition 2017 (IMO, 2020c).

Annex IV in MARPOL regulates air pollutions from ships and was first adopted in 1997. It includes among others Regulation 13 and 14 that deal with Nitrous Oxides (NO_x) and Sulphur Oxides (SO_x) emissions (International Maritime Organization, 2020j, 2020k, 2020l).

Regulation 13 is applicable to vessels built from 1 January 2000 with installed engine output power that exceeds 130 kW that are not utilized solely as lifeboats and regulates NO_x emissions. Vessels that fall under this legislation are divided in to three tiers depending on when the vessel was constructed, and each tier has three categories depending on the vessels engines rated speed that states the amount of NO_x that particular vessel can emit to the atmosphere. The latest addition to regulation 13, the tier three will be applicable in the North and Baltic sea ECAs from 1 January 2020, this will mean a substantial reduction in the amount of NO_x a vessel is allowed to emit within these areas (IMO, 2020j).

Regulation 14 governs how much SO_x is allowed in the fuel oil used onboard a ship (International Maritime Organization [IMO], 2020k). Since 1 January 2015 the SO_x limit inside Sulphur Emission Control Areas (SECAs) has been 0,10% mass by mass (m/m) and since 1 January 2020 the limit outside SECAs has been considerably reduced from 3,50% m/m to 0,50 % m/m according to IMO (2020i).

The Marine Environmental Protection Committee (MEPC) approved the EEDI and implemented the regulations in MARPOL Annex VI. MEPC extended the EEDI regulations to include RoRo passenger ships among others in 2014 thus incorporating 85 percent of ship bound CO_2 emissions in regulatory framework (International Maritime Organization [IMO], 2020h).

2.2.1.3 STCW

To formulize standards for seafarers IMO adopted the International Convention of Training, Certification and Watchkeeping in 1978. The convention entered in to force in 1984 and regulates what competence seafarers should have depending on their role onboard, engine power and where the vessel operates. The code is made up of Part A, that is mandatory and Part B that contains recommended guidelines to support the implementation of said convention. STCW requires that whoever issued a specific certificate is approved by the government of the member state (International Maritime Organization [IMO], 2020e).

2.2.1.4 International Safety Management Code

Chapter IX in SOLAS states that all passenger craft as o 1 July 1998 should implement the ISM code. The International Safety Management code (ISM code) requires the responsible party to adopt a Safety Management System (SMS). The aim of the code is to create a direct link between the crew of a vessel and the shore-based management of the company (International Maritime Organization [IMO], 2020f).

2.2.2 Swedish Transport Agency

The Ministry of Enterprise and Innovation is responsible for the Swedish Transport Agency. The Swedish Government determines the objective, guidelines of the Swedish transport agency and the amount of funding it will receive (Swedish transport Agency [StA], 2018). The Swedish transport agency is responsible for monitoring and regulating the following modes of transport: aviation, railway, road traffic and shipping (StA, 2018). The authority monitors that all ships (foreign and Swedish) in the Swedish territorial waters follow the applied regulations (StA,2018). Transportstyrelsen (2019) states “Sweden became a member of the IMO 1959”.

2.2.3 Classification societies

Flag states often employ the Recognized Organization code (RO-code) published by IMO in order to determine whether an organization is suitable to preform surveys and inspections as mentioned in SOLAS and MARPOL (International Maritime Organization [IMO], 2020g).

These duties are often allocated to classification societies that are organizations devoted to that purpose. The dominant classification societies are organized through the International Association of Classification Societies (IACS).

IACS has 12 member Societies that together “regulate more than 90 % of the world´s cargo carrying tonnage” (International Association of Classification Societies [IACS], 2020). The IACS is a nonprofitable organization and has been granted consultative status with the IMO since 1969.

The Swedish transport agency has negotiated agreements with the following classification societies according to Transportstyresens författningssamlingar (TSFS 2016:3);

- American Bureau of Shipping (ABS)
- Bureau Veritas (BV)
- DNV GL AS (DNVGL)
- Lloyd´s Register Group Ltd (LR)
- Rina services SpA (RINA)

2.3 General Engine arrangement on a RoPax

Depending on what the vessel is built for there is usually a pre-determined engine arrangement according to Kees (2012a). Ådnanes (2003) states that there are different types of engine arrangement’s for RoPax vessels where two of them are; mechanical propulsion and diesel electric propulsion. According to Encyclopedia Britannica Online (Types of ships, 2020) definition of a roro vessel, a common engine arrangement is to have a pair of compact two-engine units united with a gearbox. That are placed on either side of the vessel to allow room for a ramp to the lower cargo deck illustrated in figure 2.

According to Kees (2012b) four stroke engines are used on ferry’s and passenger ship´s because they have lower height, they are connected to the shaft through a gear box so that the propeller can be stopped without stopping the engine

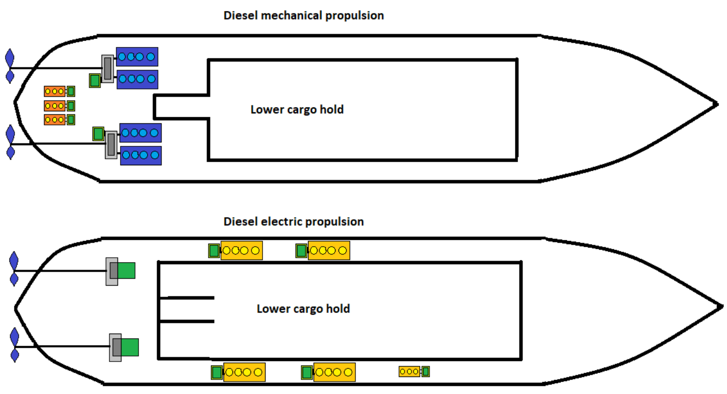

Figure 2. Engine arrangement on RoPax (Authors own copyright)

The same principal about saving space is applied when using diesel electric propulsion. The absents of a mechanical connection between engine and drivetrain allows for flexibility with engine placement. One method to save space is placing the engine units along the hull on both sides of the vessel thus extending the cargo hold according to Ådnanes (2003) and Kees (2012b).

2.3.1 Mechanical propulsion

The propeller is connected to the engines through a gearbox, the advantage with this setup is that there are only three power conversion stages; propeller, gearbox and engine. According to Geertsma et al. (2017) fewer conversion stages on this setup result in less losses in the power transfer. "*Mechanical propulsion is particularly efficient at design speed, between 80 and 100% of top speed*" Geertsma et al. (2017). The drawback of mechanical propulsion is that when the vessel is operation under 70 percent of top speed, the engine will be running inefficiently according to Geertsma et al. (2017).

2.3.2 Diesel electric propulsion

According to Kantharia (2019b) there are two common types of electric propulsion systems; shaft line propulsion and pod propulsion. Ådnanes (2003) states that the advantage of diesel electric propulsion is freedom of placement, this arrangement can be installed at the most convenient location on the vessel and does not need to be directly in line with the propeller shaft. A RoPax vessel is intended as both a passenger and wheeled cargo carrier thus have a higher demand on its power grid associated live cargo. It is advantageous to install diesel electrical propulsion when there are varied load demands and can reduce fuel consumption and prolong engine maintenance intervals according to Ådnanes (2003). When the demand for load power decreases or increases there is the option to either stop or start one of the engines, to make sure that they are running on their optimal load point Geertsma et al. (2017). This will lead to fewer running hours on the engine's and will result in reduced maintenance cost according to Kees (2012b). Ådnanes (2003) further states that the downside with diesel electric propulsion is that when running on full load the losses in the transmission from the diesel engine to the propeller will exceed the losses that occur in diesel mechanical propulsion transmission.

2.4 General power grid on a RoPax

An electric power grid is essential on modern vessels, it's used to deliver electric power generated or power kept onboard to electric consumers. Requirements from SOLAS dictate that vessels on international voyage need to have redundancy in the electric system, there is a need to have two separate systems that are able to produce electricity that by themselves cover the vessels need's for safe voyage according to Alanen, Leepälä, Lindell, Vahtera, Haimila., (2017).

Commonly a diesel generator is used to produce electricity onboard, the working principal is that chemical energy is converted into electrical energy. An engine is the contributor of mechanical rotational energy and a generator converts the energy to electric power. Vessels can also have a shaft generator that is connected onto a gearbox that's between the propeller shaft and the main engine. When a ship is on voyage there is the option to use the shaft generator to produce electric energy for the ships power grid. (Alanen et al., 2017)

The Kongsberg simulator is an educational tool that contains multiple types of vessels that are used in different courses in the Marin Engineering Program at Chalmers University of Technology according to Johan Eliasson (2020), director of studies at the Marine Engineer Program.

M22 is a simulation of a typical RoPax vessel that is able to mimic how an actual power grid functions onboard in different operational conditions according to Johan Eliasson (2020). The M22 simulation contain two main engines "Pielstick 10-cylinder V engine", two 600 kW diesel generators (DG), two 600 kW shaft generators (SG) and one 180 kW emergency generator. There is one bow thruster (BT) and one stern thruster (ST) on the vessel (Halvorsen, 2010). M22´s electric power system is configured to be able to operate in four modes A, B, C and D illustrated in figure 3 (Halvorsen, 2010).

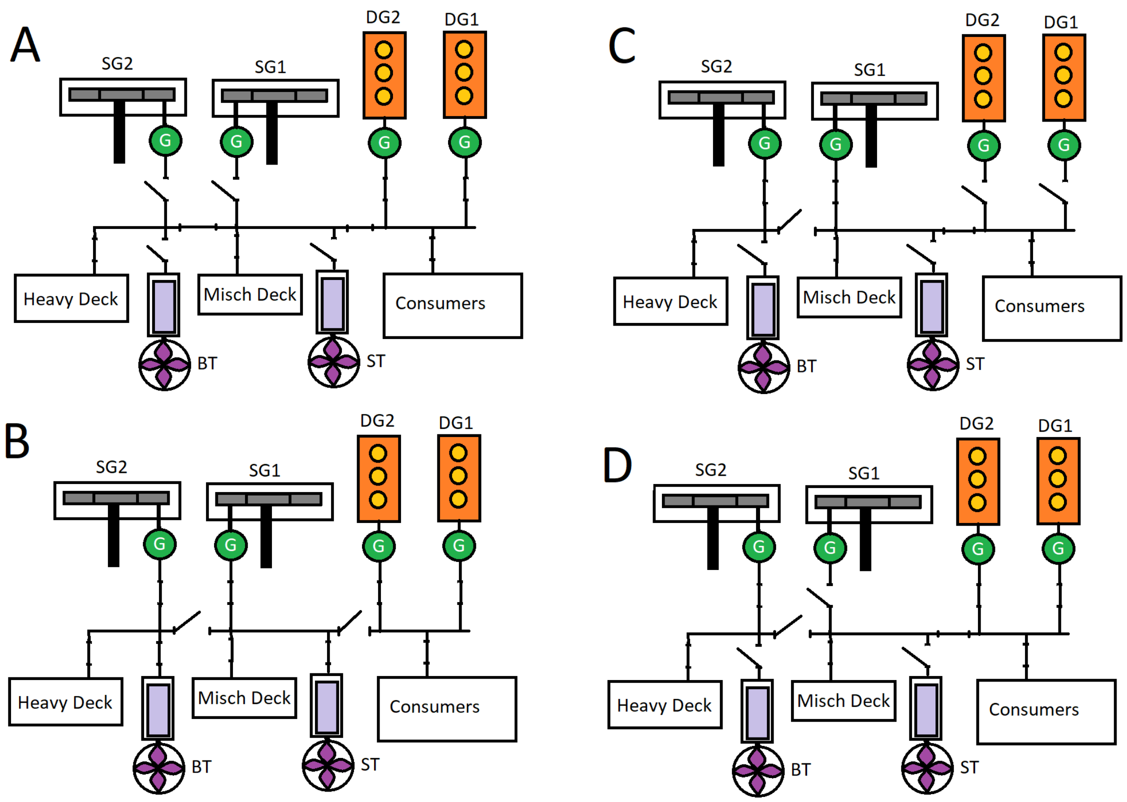

Figure 3. Illustration of the four modes of operation on M22 simulation (Authors own copyright)

A is a mode when the shaft generators are disconnected, and the generators are powering all equipment and busbars. B is a mode used when the vessel is in maneuvering mode. SG 1 powers ST and "misc. deck", SG2 powers BT and "heavy deck machinery" and the DG's power the electric consumers. Mode C is used during sea passage and there are no DG's running the power grid is supplied from the SG1 and SG2 powers the heavy deck machinery. Mode D is an alternative mode that can be used during a sea passage where SG2 powers the heavy deck machinery and the DG's powers the main consumers and the "misc. deck".

2.5 Hybrid vessel propulsion

In cases when vessels nether operate in the design speed for prolonged periods or utilize a large amount of their produced power for auxiliary loads, a hybrid propulsion system can be beneficial as described by Geertsma et al. (2017). That is particularly true if the vessel is frequently operating at low speeds and partial loads. There are multiple power systems where batteries can be integrated that are adapted to the individual vessel's needs. Electrification of vessels can be categorized in different stages. According to Hägg et al. (2018) the first stage of electrification is diesel electrical propulsion. The next stage is battery hybridization and implies that the vessel has the possibility to store electrical energy onboard. Battery hybridization can be utilized in combination with a shore connection and then be classified as a plugin-battery hybrid. The final stage is total electrification and means that all the vessels power and energy needs are covered by batteries utilizing shore power.

2.5.1 Mechanical propulsion with battery hybrid electrical powerplant

Mechanical propulsion can be combined with a battery as illustrated in figure 4. This system configuration can mitigate energy peaks and provide additional power when large load steps occur. If large load steps are reduced, the need for additional auxiliary engines running at reduced load can be eliminated (DNV GL, 2016). This system arrangement is practical when converting a vessel that is not equipped with a shaft generator to hybrid propulsion. Depending on the size of the batteries this arrangement can be used to provide power to auxiliary systems when the vessel is moored and eliminate local emissions (DNV GL, 2015).

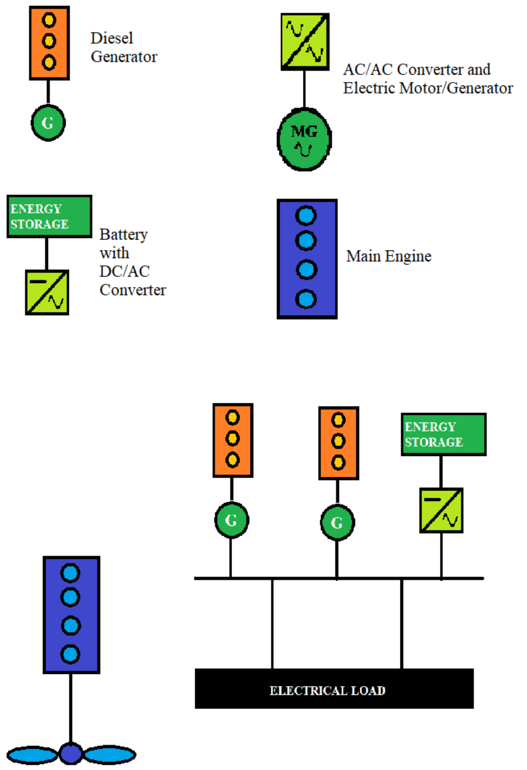

Figure 4. Typical mechanical propulsion arrangement and symbol description (Authors own copyright)

2.5.2 Hybrid propulsion system with hybrid power supply

The combination of diesel mechanical propulsion and batteries is a flexible system that can either use the prime mover for propulsion by itself or in combination with generators and batteries as illustrated in figure 5. The main engine is connected by a gearbox to a shaft generator (MG) that is in turn connected to the ships power grid by way of an AC/AC converter. The shaft generator in this configuration can be utilized in Power Take Out (PTO) or Power Take In (PTI) mode.

When the shaft generator is in PTO mode it functions as a generator. When PTI mode is activated the shaft generator operates as a electric motor using auxiliary generators and battery to provide additional propulsion power (DNV GL, 2015).

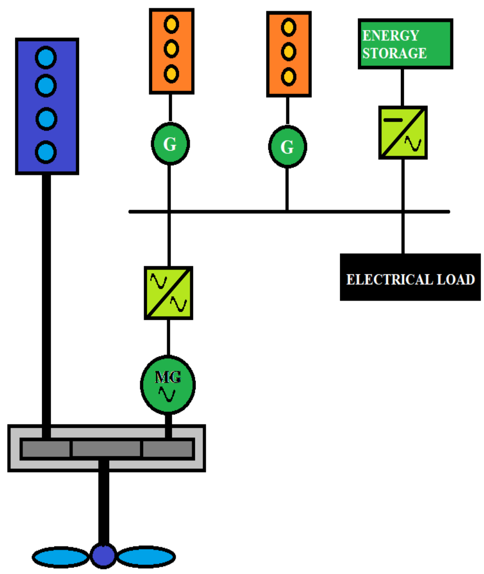

Figure 5. Typical hybrid propulsion system with hybrid power supply (Authors own copyright)

The batteries can thus prevent the loss of thrust and enable the vessel to maneuver in case of failure of the main engines (Geertsma et al. 2017).

By leveling the loads on the combustion engines, these will be able to operate at efficient operating point and the batteries can also be utilized for peak shavings. To reduce the cost for these types of installations the vessel can be built with fewer diesel engines. To minimize fuel consumption in these systems it is important to have a well formulated control strategy in order for the batteries to be charged at optimal points during operations according to Geertsma et al. (2017).

2.6 The lithium-ion battery

The need for an energy dense, compact and rechargeable energy storage device arose during the 1980´s with the development of numerous portable electronic devices. Lead-acid, nickel-metal hydride and other types of batteries utilized before the development of the lithium-ion battery (LIB) were heavy and had a limited development potential to expand their energy storage capacity. Lithium-ion batteries can deliver a voltage of approximately 3.6 V compared to the capacity of the nickel-metal hydride batterie that is able to deliver 1.2 V (Batteriföreningen. n. da). The LIB became commercially available in the early 1990´s and has since then become prime energy storage (Pistoia, G. 2014).

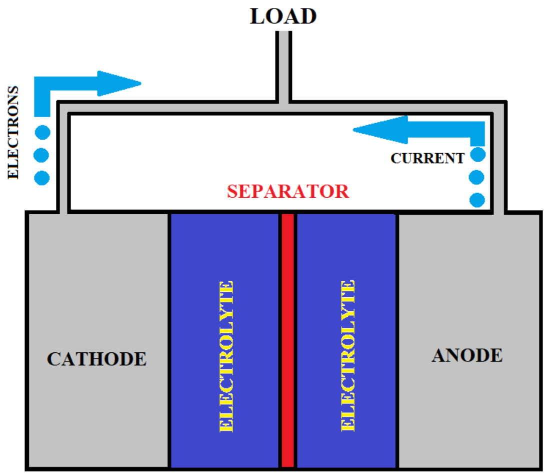

Figure 6. Lithium-Ion cell discharge mechanism (Authors own copyright)

The LIB cell is comprised of cathodes and anodes divided by a separator as shown in figure 6. These are contained in a medium called electrolyte. The separator separates the positive and negative electrodes while still allowing the ions to pass through. The anode is usually comprised of a graphite mixture or other carbon-based materials. The cathode is predominately some type of metal oxide, in maritime applications lithium nickel manganese cobalt oxide is typically used (Hägg et al. 2018: Batteriföreningen. n. db).

In applications were one cell is insufficient to provide the necessary power they can be grouped together into battery modules. These modules are equipped with thermal monitoring and management systems as well as safety and control functions. Modules can be combined to form a battery pack containing additional protective devices and monitoring systems.

Lastly modules can be joined to form a battery system that incorporates structural fire protection, fire suppression and additional cooling. The LIB is controlled by a Battery Management System (BMS) that is incorporated in the different components that make up the system (American Bureau of Shipping [ABS], 2017). According to J. Stranne (personal communication, 16 march, 2020) a LIB cell should never be fully charged or discharged to retain maximum life expectancy of the cell. Instead when charging the LIB, the level of charge should not exceed 90-95% and should also never be fully discharged.

According to Hägg et al. (2018) battery installations as of now are limited to approximately 4 MWh and that it is primarily vessels that transit shorter distances that are totally electrified. While the cost of LIB batteries is receding nearly all large installations are granted subsidies when financing the projects (Hägg et al. 2018).

2.6.1 Battery safety

While providing the advantage of being able to provide high power and high energy the use of lithium-ion batteries is not without risk. Abnormal abuse conditions can damage the LIB which can cause catastrophic failure of the battery according to Pistoia, G. (2014) and Jianwu, W., Yan, Y., Chumhua, C. (2012).

The safely issues that may occur are primary caused by the failure of one of the batteries main components, and as such it is important to control variables that can affect these. Variables such as voltage, temperature, pressure and current need to be monitored and controlled to minimize the risk of critical failure (Jianwu, W., Yan, Y., Chumhua, C. 2012).

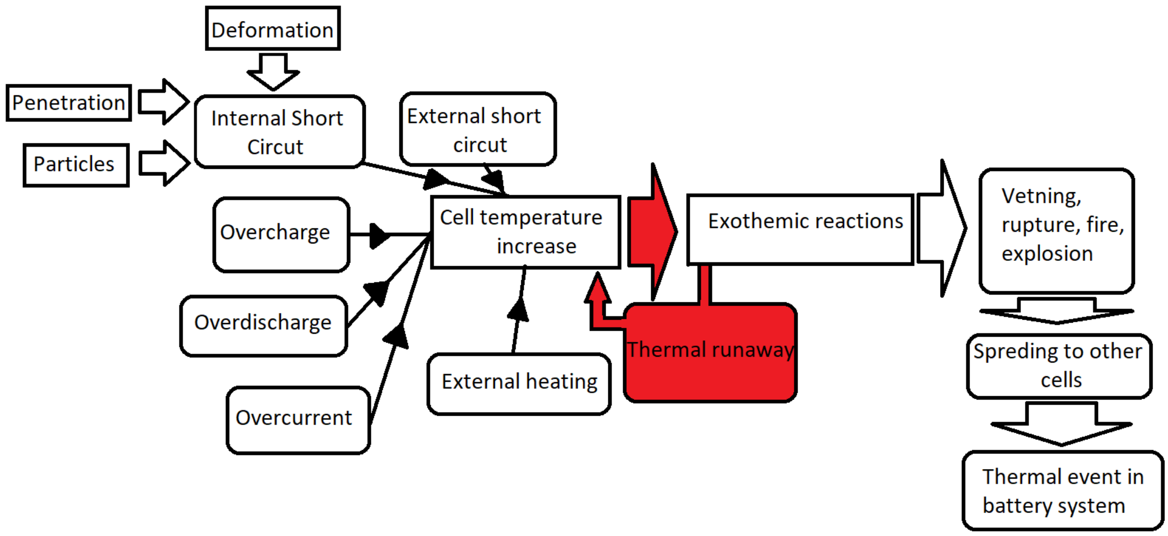

Figure 7. Factors that can contribute to a thermal runaway (Authors own copyright)

Because of the high amount of energy contained within the LIB several factors such as short circuits, overcharging of the battery, BMS failure or exaggerated currents when charging can result in an unstoppable chain reaction in the cell (DNV GL, 2016). This self-sustained chemical reaction is referred to as a thermal runaway and can rapidly spread to adjacent cells and other battery modules in its proximity and can eventually engulf the whole battery installation as illustrated in figure 7.

It is stated in DNV GL (2016) that during a thermal runaway the cell temperature normally exceeds 200 °C but can go as high as 800 °C in some cases. The chain reaction causes materials in the cell to break down and creates gasses that are usually flammable, toxic and it is important to ventilate these gases away from the installation.

When dealing with a LIB fire the choice of medium for fire suppression is varied depending on the chemical composition of the battery. Some cases it may be unsuitable to use water and in other cases the reaction is able to produce oxygen by itself. Generally, the preferred method is to cool down batteries and simultaneously deny the fire access to oxygen (DNV GL, 2015).

According to the IMO guidelines a Hazard Identification (HAZID) survey needs to be conducted prior to operating a LIB system onboard a vessel. The aim of the survey is to evaluate how the LIB-system performs during operation and to identify potential risks according to Hägg et al. (2018).

2.7 Legislation around batteries

Swedish vessels that aim to implement batteries onboard need to comply with both national regulations as well as the regulations from the vessel's classification society.

2.7.1 Swedish transport Agency Guidelines

The Swedish transport agency released an article with guidelines for battery and hybrid driven vessels during 2018. The authority has observed that battery powered, and hybrid driven vessels have gained popularity among Swedish ship owners (TSG 2018-735). The guidelines prescribe that before a reconstruction or the building of a new vessel, contact shall be made with the Swedish transport agency (TSG 2018-735). This is done to ensure that the vessel is built according to relevant regulations.

Swedish vessels are divided into two main categories: International traffic and national traffic (TSG 2018-735). The Swedish guidelines states that Swedish vessels meant for international traffic is regulated by TSFS 2014:1 and vessels meant for national traffic are regulated by TSFS 2017:26. There are general regulations focusing on the safety aspect of battery installation but these do not incorporate specific requirements (TSG 2018-735). The guidelines apply to vessels whose main propulsion is powered by battery, battery hybrid vessels and vessels that use batteries as an auxiliary power source or for emergency power.

TSG 2018-735 dictate that crewmembers responsible for operating, performing maintenance or part of fire safety organization onboard need to have relevant education and knowledge of the battery pack installed onboard. Emergency situations, operation and maintenance needs to be addressed in the education of the battery pack.

2.7.2 Lloyds Register

Lloyds Register (LR) was the world's first classification society, founded 1760 by customers of Edward Lloyd's coffee house in London whose aim was to give merchants reliable information about the condition of their vessels (Lloyd's Register, n.d).

Lloyds register have assembled guidelines for battery installations that are applicable on both fully electrified vessels as well as hybrid vessels (Lloyd's Register, 2016). Lloyds found it impractical to formulate prescriptive rules that encompass all battery installations because of the vast range of cell chemistries and continually evolving technologies. Instead Lloyds opted to adopt a risk-based approach they refer to as "Approval in Principle". This means that Lloyds treats all battery installations as novel designs and is involved from the concept stage to ensure that the installation in safe and doesn't compromise other safety systems onboard. Approval in Principle have been used by Lloyds in the classification of several battery installations according to Lloyd's Register (2016).

2.8 Stena Jutlandica

Figure 8. Stena Jutlandica (Authors own copyright)

Stena Jutlandica (figure 8) is a RoPax Vessel traveling between Gothenburg and Frederikshavn, with a passenger capacity of 1500 and 500 cars according to Michaelsen (2018). Stena Line (2020) states that the vessel was built 1996 and its length over all is 184 m. To produce electricity onboard Stena Jutlandica utilizes four diesel generators (DG) sometimes referred to as auxiliary engines. These can provide 1740 kW each to a total amount 6960 kW. While the vessel is moored in Gothenburg the electrical needs for hotel load are provided through an electrical shore connection that can provide 1600 kW according to J. Stranne (personal communication, 16 march, 2020) First Chief Engineer on Stena Jutlandica.

The engine department onboard Stena Jutlandica is composed of 11 seafarers. Five of these are officers and are comprised of one chief engineer, one first engineer, one electrical engineer and two second engineers. The vessel crews rotate according to a predetermined schedule according to J. Stranne (personal communication, 16 march, 2020).

According to J. Stranne (personal communication, 16 march, 2020) the idea behind the conversion to a battery hybrid auxiliary system originated from Stena Technology. J. Stranne (personal communication, 16 march, 2020) further states that the concept was born while an employee with an electric bicycle was charging his battery and realized that it might be possible to do in a grander scheme.

Stena Lines Denmark terminal in Gothenburg was already equipped with a high voltage shore connection for ships and said connection was able to deliver more power than used by the vessel while moored (J. Stranne, personal communication, 16 march, 2020). The reason for choosing Stena Jutlandica over other vessels working on the Gothenburg - Frederikshavn rout was mainly due to the vessel having good stability and being able to add extra weight without compromising safety.

The lack of similar systems led to a Research and Development project (R&D project) between Stena Line, Stena Teknik and Trident Callenberg that was chosen as the contractor according to J. Stranne (personal communication, 16 march, 2020). The project consisted of developing the whole system, including the control system, layout and where to house the LIB. Due to there being no prerequisite classification legislations Stena Line together with Lloyd's Register Group Ltd, had to perform a major risk analysis to be able to class the installation. The analysis was by gathering expertise from a variety of fields of study relatable to the project. This in turn became a report that Lloyd´s used as template to create guidelines and regulations for future hybridization projects (J. Stranne, personal communication, 16 march, 2020).

A prerequisite for performing the conversion was to receive financial support for the project. This was archived through collaboration with European Union and the Swedish Transport Agency. The budget for the project was projected to be 25 million Swedish Kronor of which Stena Line provided approximately half of the funding according to Hägg et al. (2018). The cost of the actual battery's was approximately 25 % of the total cost according to J. Stranne (personal communication, 16 march, 2020). The remaining expenses included the installation cost as well as the additional wires and other hardware needed to connect the Energy Storage System (ESS) to the ships power grid.

J. Stranne (personal communication, 16 march, 2020) states that the battery installation is composed of two separate parts that were integrated into two different compartments in a 24-foot shipping container that was installed on the weather deck aft of the vessel as illustrated in figure 9. According to J. Stranne (personal communication, 16 march, 2020) it's possible to use the battery's separate but in normal operational conditions both batteries are always connected to the main buss-bar. Stena Line have opted to address the instantiation as a battery generator (BG) J. Stranne (personal communication, 16 march, 2020) further states. Onboard the system is sometimes referred to as a backup system or a blackout prevention system. Figure 10 illustrates the power grid before the installation of the ESS.

Figure 9. Shipping container housing the batteries (Authors own copyright)

The battery pack chosen for the installation was the Corvus Orca Energy Storage System produced by Corvus Energy (Corvus Energy, 2018). The battery installation can deliver 3 MW of power momentarily, together the batteries have a capacity to deliver 1 MWh (J. Stranne, personal communication, 16 march, 2020). The installation was delivered with a five years warranty based on the expected cycle the battery would be utilized in. This was made possible by regulating the state of charge. In order to prolong the battery lifetime Stena Line decided to limit how many percent of battery capacity that can be used before the battery is perceived as empty or full (J. Stranne, personal communication, 16 march, 2020).

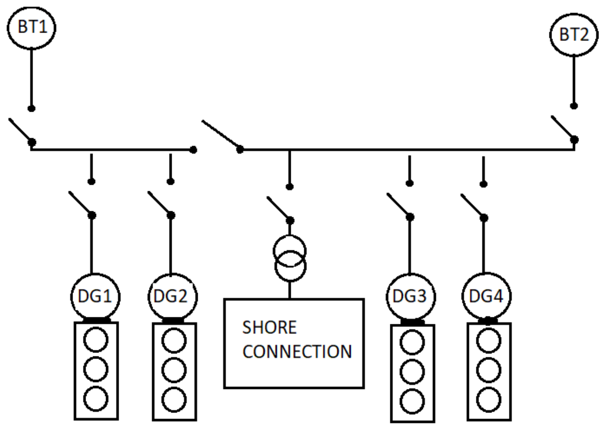

Figure 10 Stena Jutlandica busbar before conversion (Authors own copyright)

In this case the gauge in the engine control room will indicate 100 % charge when the actual value is 70 % and when gauge shows that the battery is empty the actual value is 30 %. This means that the actual capacity of the battery is rated to 400 kWh instead of 1 MW.

According to J. Stranne (personal communication, 16 march, 2020) the gauge is similar to that of a battery level indicator of an iPhone. This approach was chosen to make it easy for the engine officer to perceive the battery capacity without having to calculate the amount of power allowed to use. When the ESS was put to use Stena Line realized that they were not utilizing it as extensively as was originally planned and thus further extended the expected lifetime of the battery's to approximately nine years according to J. Stranne (personal communication, 16 march, 2020).

According to J. Stranne (personal communication, 16 march, 2020) the major changes to electrical system were the addition of two large circuit breaker that were installed on the main switch board down in the engine room this were connected to the battery pack as illustrated in figure 11.

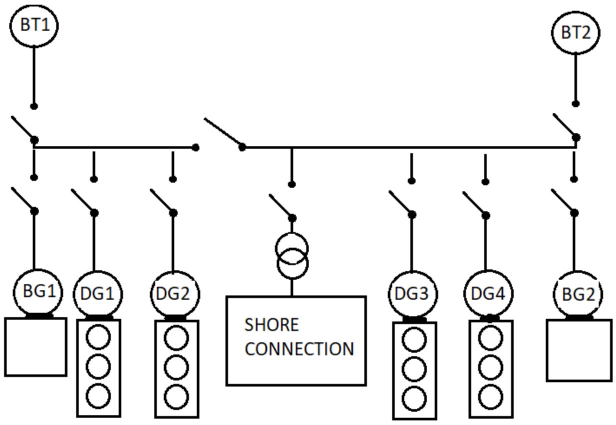

Figure 11. Stena Jutlandica busbar after conversion (Authors own copyright)

J. Stranne (personal communication, 16 march, 2020) states that the hotel load is dependent on the season and varies between 800 to a maximum of ca 1200 kw in the summer when the air-conditioning on board is in full use. The electricity from the hotel load can be provided by one auxiliary generator (DG). However, when using both bow thrusters (BT), each rated to approximately 1600 kW additional power is needed. According to J. Stranne (personal communication, 16 march, 2020) the vessel utilizes three auxiliary generators in this scenario.

3 Method

To make an assessment of how a conversion to hybrid power have affected the workload for the engineering officers onboard the group initially reviewed different scientific strategies. After a thorough investigation and with the help of "*Checklist for choosing scientific strategies*" (Denscombe, 2018, s. 28) qualitative survey was chosen as the most appropriate method. Survey methodology was chosen due to its suitability when evaluating the effect of innovations. This choice is convenient because the basis for the results can be achieved during a short timeframe and can be used to collect both qualitative and quantitative data according to Denscombe (2018). The data collection mode most appropriate for this specific task was face-to-face interviews. This mode has a high response rate and enables the researcher to validate the data immediately. Performing interviews is useful when researching complex subjects and there is a need to obtain information from key figures (Denscombe, 2018).

3.1 Data collection and Analysis

Data that was utilized in this thesis was primarily collected through interviews performed by the authors. Secondary data was gathered by examining literature relevant to the purpose of the thesis. The researchers preformed a qualitative analysis of the data gathered when finalizing their results.

3.1.1 Background material

The background for this thesis was built upon information gathered from published sources and literature through Chalmers Library, Google Scholar and other authorities in scholarly literature. In accordance with statements made in Denscombe (2018) all the sources underwent a critical literature review. The information gathered in the background was later used to formulate relevant questions for the interviews. Throughout the literature review the researchers gathered relevant keywords to expand their search parameters.

To get specific data about the vessel's retrofit to battery hybrid power made it necessary gather additional information not available online. To retain in-depth information about a retrofit the researchers determined that a background interview was necessary to be used in correlation with the examined literature.

Questions asked during the background interview can be viewed in Appendix 1. The data gathered from the interview was integrated in the background of the thesis to expand the researcher's knowledge of the subject.

3.1.2 Interviews

The interviews were performed in a semi structured manner. While utilizing a pre-determined agenda this enabled the participants to expand on subjects chosen by the researchers. Semi structured interviews also enabled the researchers to adapt the questions between interviews to investigate information gained from previous participants (Denscombe, 2018).

Personal interviews were primarily chosen because it was deemed impractical to hold group interviews on a RoPax vessel based on how such a ship is manned. Performing the interviews face-to-face was deemed to be justifiable, because of close geographical proximity to Chalmers University of Technology. According to Denscombe (2018) another advantage of conducting personal interviews is that any opinions stated during the interview can be associated to one specific source which makes coordinating the interview less complicated (Denscombe, 2018).

The interviews that were performed were categorized as either primary interviews or background interview. The interviews were recorded when consent was given by the participant. Primary interviews were conducted with available engine officers onboard the RoPax vessel Stena Jutlandica. Specific interest was aimed at officers that had served onboard both pre and post conversion. The questions for the primary interviews were compiled through meticulous deliberations to cover all data needed formulate credible results. Questionnaires for the primary interviews are available for review in Appendix 2. The background interview was conducted with the First Chief Engineer responsible for Stena Jutlandica to gain specific insight in how the vessel was retrofitted.

3.1.3 Data Analysis

The researchers transcribed the audio recordings from the interviews to enable them to analyze the and interpret the data. The data was analyzed using the grounded theory methodology. This method is appropriate when analyzing interview data according to Denscombe (2018). The data was color coded and categorized depending on which of the research questions it correlates with. The categorized data was further analyzed to enable the researchers finalize key concepts that correspond to their predetermined research questions.

3.2 Reliability, validity and generalization

According to Denscombe (2018), qualitative study based on few interviews might not reflect on what other people in a similar working position might think or feel. The draw back on qualitative studies are that they might not get the same result if they are reproduced. To make a reliable study it needs to be well documented and a clear method structure needs to be followed so that other researchers can follow the reasoning what lead to the conclusion.

Denscombe (2018) states that it can be hard to judge if someone is credible during an interview however there are ways to validate credibility. If a result is based on an exclusive interview it might not be fully credible but if it's something multiple participants confirm it might be reliable. The people that participated in the survey, are all responsible on different levels for the operation of the vessel and by so have a high validity to this survey. Because qualitative research utilizes a limited number of sources it is not always possible to generalize the results on similar cases Denscombe (2018).

3.3 Ethical Considerations

While performing the survey ethical principals were followed to ensure that the thesis is in agreement with the moral guidelines of the institution. To ensure that no physical, psychological or personal harm befalls the participants all data collection was preformed confidentially, and steps were taken to safeguard their personal integrity (Denscombe, 2018). The interviews were all voluntary and consent to use the gathered information was requested from the participants. Before the interview's participants received a written summary about the aim of the research as stated by Denscombe (2018).

4 Results

Information gathered from interviewing five engineering officers onboard a RoPax ferry is presented in the following chapter. The results from interviews were summarized to answer study the questions stated in chapter 1.2. The prementioned officers will be addressed as “Chief Engineer”, “First Engineer”, “Electrical Engineer”, “Second Engineer A” and “Second Engineer B”. Questions asked in the interviews can be found Appendix 2.

4.1 Operational changes

According to the Chief Engineer the vessel has experienced major changes to its everyday operations after implementing the ESS onboard. The Electrical Engineer, who was present both during and after the installation of the ESS states that the onboard routines for auxiliary power generators have been altered after the implementation of battery generators onboard. According to First Engineer there are three modes of operation for the auxiliary generators during voyage each with different power requirements. Prior to the conversion the vessel used two auxiliary generators while maneuvering in the archipelago or when approaching port. When the bow thrusters were in use and power consumption peaked the vessel utilized three auxiliary generators and lastly during sea passage only one auxiliary generator was needed. According to Second Engineer A the number of auxiliary generators used during sea passage can vary depending on whether conditions, bad weather entails for more redundancy on the power grid due to safety reasons.

Chief Engineer states that following the installation the battery generators are always connected to the electrical power grid. After the conversion the need for power supplied by auxiliary generators has been reduced. While maneuvering in the archipelago and near port the vessel now only utilizes one auxiliary generator and relies on the ESS to cover the additional power demands. According the Electrical Engineer one battery can cover the power demand for one bow thruster. This implies that the ESS have the capacity to cover the power demand for both bow thrusters. This reduces the need for more than one auxiliary generator when maneuvering with bow thrusters. During sea passage the vessel still uses one auxiliary generator while the battery generators are connected and used for peak shaving.

Chief Engineer states that the system was specifically designed to eliminate the need for the engineer manning the control room to continuously monitor battery charge level. Instead this feature is integrated into the ship's PMS. If the need for more power arises the PMS automatically starts additional auxiliary generators that are kept in standby according to prioritization. The system was not programmed with the ability to automatically shut down auxiliary engines for the sake of safety. This was done because the engineers did not want the system to reduce the number of auxiliary generators in use without proper authorization.

The charging of the battery generators can occur either in Gothenburg by means of shore connection or by using auxiliary generators onboard according to Chief Engineer. Right now, half the energy used in the battery generator originates from shore and the rest is provided by auxiliary generators. The system is equipped with a function called "Shore Power Charging" that when activated inhibits the system to utilize energy from the generators. This was done so that the engineers onboard could turn off the automatic charging and drain the battery generators sufficiently to maximize charging from shore connection.

Chief Engineer further states that a reset button was integrated into the system, when used it would disconnect the battery generator breakers from the main switchboard. This would revert the system to its original state prior to the addition of the ESS.

During the interviews the First Engineer conveyed "*We save both fuel and running hours on the auxiliary generators and this means that the intervals between scheduled maintenance can be prolonged because they are based on running hours*". The reduced running hours on the auxiliary generators have caused the circuit breakers to have a prolonged lifetime expectancy according to the Electrical Engineer. He further states that there are few problems that have occurred related to the EES installation, but those that have occurred are usually so complicated that we had to consult with experts. The reduced use of auxiliary generators has also resulted in fewer fuel leaks in the engine room and extended service intervals on auxiliary generator fuel injectors.

"There is no maintenance to perform on the ESS that we are able to perform ourselves" stated the Chief Engineer. He further states *"But we have added an inspection of the container housing the ESS in the watchkeeping Motorman's daily routine, but this doesn't imply an added workload because he needs to inspect adjacent areas anyway"*. The container is further equipped with cameras which enables live monitoring of the batteries from the control room.

There have been some additional tasks implemented in the maintenance planning program Amos that have to do with the ESS. This include changing of air filters once a year which takes approximately one hour and testing of emergency systems.

The Chief engineer noted a reduced level of noise in the engine room which has improve the working environment for the engineering crew. The noise level has also dropped inside the engine control room, this was done by implementing motor soft starters that instead of delivering 500 A slowly increase the electric current from 900 A to desired output.

4.2 Primary benefits of the installation

When the engineers were questioned whether they felt safer in their profession after the installation, they unanimously expressed positive opinions.

When asked about what the primary benefits with the installation were the Chief Engineer stated, "*The main benefit of this installation has been the insurance that there is enough power onboard that can be utilized quickly, even out peaks in power consumption and blackout prevention*". With so many passengers onboard as well as other consumers a blackout should be avoided at all costs. Chief Engineer conveyed that one of the primary reasons they spent a lot of money to develop this particular system was to implement a blackout prevention function onboard. According to the Chief Engineer the blackout prevention functions similarly to an Uninterrupted Power Supply (UPS) system. But it is important to keep in mind that the system is not approved to function as an emergency system by the classification society. "*To get the battery installation classified as an emergency system would be like opening pandoras box*" This means that the emergency switchboard is intact and has not been altered by the installation of ESS. If somehow the ESS would fail to take over the load during a blackout the emergency generator would can be engaged and provide power to essential systems. Other benefits according to the Chief Engineer were reduced running hours and savings in fuel costs.

Apart from saving fuel the First Engineer was of the opinion that blackout prevention was the main benefit gained by installing the ESS which he believed could sustain the vessel for proximately 30 minutes. During the interview the First Engineer stated that" *Even if you force the system to blackout the lights will not even flicker*" and *"I think this is an awesome system and it feels like the future".*

The Electrical Engineer believed that blackout prevention was the major benefit followed by the environmental gains resulting from lower emissions due to reduced fuel consumption. He also mentioned saving in spare parts as a benefit because of reduced maintenance needs particularly less wear on circlet breakers.

Second Engineer A thinks that the blackout prevention is the primary benefit of the installation. He stated, "*I feel very safe knowing that even if I get a blackout, I still have enough power to keep the essentials running*". Other benefits are the saving of running hours on the auxiliary generators which causing lees maintenance requirements and a reduced amount of emissions.

According to Second Engineer B the main benefit of the ESS is the blackout prevention.

4.3 Primary disadvantages of the installation

The Chief Engineer believed that while the installation was time-consuming and costly the result was seen as successful by both the company, contractors and crew. The installation didn't cause any issues when performing the risk analysis or cause any problems in the crews working environment. Chief Engineer further stated that his only concern was the risk associated with having a large battery onboard. *"As long as it is a permanent installation, done by the book, according to regulations and different scenarios have been contemplated I feel safe".*

First Engineer conveyed that the primary disadvantage was to have to *"familiarizes with a new system that is very sophisticated and not being able to fix any issues that occur without having to call in experts*".

The Electrical Engineer mentioned that the main disadvantage to the ESS is that it´s rather High-tech installation. The ESS reacts so fast that the older mechanical systems don't have enough time to react and can sometimes start giving of alarms due to that. This makes it hard to figure out what's going on if a problem occurs. He further states that there have not been any major problems yet and the installation feels reliable.

Both Second Engineer A and B voiced that fire hazard is the only disadvantage they can think of that involves the ESS. Second Engineer A also mentioned that because of the installation was a R&D project, new regulations may still be developed and implemented in the future.

4.4 Effects on the emergency organization onboard

When the researchers inquired about how the safety organization had been affected by the implementation of the ESS the engineering officers gave a varied response. The Chief Engineer disclosed that the crew had been educated in how to respond to a potential fire in the container housing the ESS. The education package was produced by Stena Line in collaboration with the contractors involved in the ESS installation. Because of the highly toxic nature of the gasses that develop during a battery fire, that can penetrate personal protective equipment a fixed firefighting system was employed to minimize exposure. This system is remotely operated, and the hazardous areas can be continuously monitored through CCTV. The thermal runaway pipes are designed to extract any hazardous gases and release them above the container housing the ESS where they will be diluted. Because of the explosive nature of these gases an explosion hazardous area spanning three meters was established to eliminate any potential ignition sources in the vicinity of the ESS. The fixed firefighting system utilizes condensed aerosol suppressants with four nozzles mounted in the container and three in the converter room. There is also fixed equipment mounted outside of the container that can be used to cool the walls of the container if the aerosol is unable to quench the flames inside.

Second Engineer A mentioned that the authority to trigger the aerosol fire suppression system is held by the Chief Engineer and that he in his role as Second Engineer was also the appointed leader of the safety group onboard. The researchers were told that a bonus of the training the crew received was that they now felt more confident in how to act in the event of a fire in an electric vehicle being transported onboard.

4.5 Summary of results attained from interviews

The interviewed engineers all remarked that blackout prevention was primary benefit attained from converting Stena Jutlandica to battery hybrid auxiliary propulsion. Other benefits from the conversion were longer intervals between maintenance on auxiliary generators as a result of normally using only one generator since the conversion. The utilization of the ESS for peak shaving has increased the efficiency of auxiliary generator being used at the time. The reduced use of internal combustion engines onboard has led to savings in fuel usage with the added benefit of lowering emissions from combustion.

The primary disadvantage from the installation that most of the engineers mentioned was the risk of being exposed to a lithium-ion fire onboard, this opinion was predominant with the Second Engineers who are part of the fire groups that will respond to a possible fire hazard. The engineers also voiced concerns with the complexity of the new system. This in turn makes them reliant on outside experts to resolve some issues thus making them less self-reliant.

The conversion has affected the emergency organization onboard thru the introduction of a large lithium-ion battery onboard. This prompted Stena Line to collaborate with the contractors to develop an education package for the crew on how to combat a possible fire in the ESS. Because of the toxic nature of the gasses that develop during a lithium-ion fire the vessel primarily relies on fixed firefighting equipment to combat the threat thus limiting exposure to crewmembers.

5 Discussion

The purpose of this thesis was to investigate how the engineers perceive a battery hybrid auxiliary system and how the conversion affected the day to day operation of the engineers. In this chapter we will discuss the result of the research questions and the method used. Part 5.1 will discuss how the chosen method impacted the study followed by 5.2 where the results will be evaluated. Lastly in 5.3 the authors will discuss the quality of the preformed study.

5.1 Method discussion

The primary data collection was performed by conducting interviews with relevant engineering officers onboard. Due to the onset of Corvid-19 in Sweden the majority of company's introduced strict regulations regarding meetings and visitor interactions to limit exposure, this included Stena Line that was the study´s planned interview target. The originally envisioned scenario was to perform face-to-face interviews on two different occasions to gather data from multiple engineering crews, however the research had to be adapted to a different data collection method to take into account prevailing circumstances. The most suitable data collection method was perceived to be telephone interviews and this approach was acceptable to the target group.

The interviews were performed on multiple occasions to minimize impact on their daily routines. The semi-structured form enabled the researchers to ask follow-up questions to develop the subject and gain additional data that was not originally considered during interview planning. The background interview was performed with the First Chief Engineer onboard Stena Jutlandica and was very informative and deemed to be accurate because of his involvement throughout the conversion.

One of the officers interviewed had not been employed as an engineer during the convention but had worked as a Motorman onboard at the time. Due to his prior knowledge of the vessel the researchers deemed his opinions during the interview to be reliable.

5.2 Result discussion

The conversion to a battery hybrid auxiliary system onboard Stena Jutlandica has by and large had a positive reception by the engineering officers. The ability to utilize only one auxiliary generator in day-to-day operations has been beneficial to many aspects of the engineer's daily work. The way the systems were incorporated alongside existing systems was done with ease of operations in mind. The ability to reset the power system to its original configuration at the push of a button seem particularly useful while the crew is still learning how to operate the system and all the kinks still have not been worked out.

That all engineers stated that blackout prevention was the primary benefit of the installation, this in itself is not surprising. The engineer's role onboard is essentially to ensure that the vessel is seaworthy and able to transport cargo to its intended destination and a blackout basically renders the vessel dead in the water. A blackout onboard any vessel is not desirable and onboard a vessel carrying passengers even more so because of how unpredictably people react to unexpected situations. The ability to use the ESS instead of starting additional auxiliary generators is beneficial in several ways as described by DNV GL (2016). The maintenance intervals increase, thus giving the engineers more time to maintain other systems similarly to when a vessel is powered by diesel electrical propulsion (Ådnanes, 2003). Wear and tear on auxiliary generator parts is also reduced thus saving the company money by reducing the needing for spare parts to be kept onboard. The ability of utilizing the system for peak shaving is a useful feature as described by Geertsma et al. (2017) and enables the engineers to employ the auxiliary generator more efficiently. This also reduces the amount of fuel the auxiliary generators consume which is both advantageous from an economic standpoint as well as environmental.

Both the Electrical Engineer and the First Engineer voiced opinions about the system being technically advanced. Similar opinions have been voiced by others in the shipping industry because of the rapid development of some new technologies that have ended up on ships. Unfortunately, this is a reality engineering officers must accept and adapt to for the time being. The researchers believe that some of the negativity the officers feel towards the new system is caused by them not being expected to maintain the system themselves and instead having to rely on contractors.

The researchers further speculate that mariners being an independent lot don't appreciate having to rely on others because if anything happens on a voyage help can be a long way off.

Second Engineer A and B both expressed concern about the lithium-ion battery being a potential fire hazard. Because of their role as leaders of a fire group that needs to respond to a potential fire, they most probably have the most at stake in the event of a fire onboard. The rapid reaction that develops during a thermal runaway in a lithium-ion cell is hard to discontinue and dangerous to approach (DNV GL, 2016). This entails them to rely on the fixed firefighting systems to contain the resulting fire as to avoid exposure to toxic fumes (DNV GL, 2015).

A reduction in noise levels occurred because of the conversion according to the Chief Engineer. While not being conveyed as a primary advantage by the Engineers the researchers believe that this could have significant positive effects on the working environment. Our personal experience onboard Swedish merchant navy vessels as engine cadets has illuminated how difficult communication in a noisy working environment can be. Reduced noise levels could both benefit crew safety by improving communication and crew health by reducing stress caused by the constant noise and potential loss of hearing.

The researchers learned that the conversion of Stena Jutlandica was partly financed by the European union and the Swedish transport agency according to J. Stranne (personal communication, 16 march, 2020). This is consistent with the information attained while compiling the background for the thesis where it was mentioned that almost all big LIB installations receive financial subsidies (Hägg et al. 2018). While this study indicates that there are many advantages to be attained from installing an ESS it seems that the technology still has to be developed further. The installation is potentially economically sound, however the question still lingers if it would be financially feasible to perform similar conversions without public funding.

This thesis has been focusing on the operational changes the ESS installation brought to the engineers onboard, thus the environmental implications have not been prioritized. The benefits to the environment that the researches can see after conduction this study is that the ESS installation promotes Stena Jutlandica to only use one auxiliary engine in day to day operation.

Prior to the installation they used multiple auxiliary engines in the operation of the vessel, from this we can conclude that the battery installation has reduced emissions produced by the auxiliary engines.

While this research was not focused on the environmental impacts from the conversion, the researchers could speculate that the conversion is an environmentally sound investment in relation to SO_x, NO_x and CO_2 emissions from ships.

All new RoPax vessels must comply with the 2014 EEDI regulations according to Tzannatos & Stournaras (2015) thus making it likely that further investments will be made in technology's that can reduce CO_2 emissions. While Stena Jutlandica predates the NO_x tier requirements (IMO, 2020j) it's in Stena Lines interest to project the company as an environmentally conscious business venture thus profiting from reduced emissions accomplished by the ESS. According to IMO (2020i) the 2020 SO_x regulations do apply to Stena Jutlandica and while the ESS dos does not exempt the ship from these regulations the authors believe that the investment in battery generators may pay off in electrification of future ships while also reduce consumption of expensive low sulphur fuels on existing vessels. Because Stena Jutlandica lacks shaft generators the researchers believe it´s unlikely the vessel will be converted further to hybrid propulsion system with hybrid power supply.

The choice of where to place of the ESS onboard Stena Jutlandica was made with fire safety in mind. The design of the vessel enabled the Stena Line to add the container housing the LIB on the aft portion of the weather deck above the ramp. The placing of the battery above deck enables the crew to isolate the LIB in case of a thermal runaway and thus reduced the risk of exposing the personal to toxic gasses that occur during the chain reaction inside the battery installation mentioned by DNV GL (2016). The LIB's placement further enables the crew to cool down the installation from the outside with fixed firefighting equipment as stated by DNV GL (2015). The placement of the battery depends on the layout of the vessel and what the classification society deems acceptable. Lloyd's Register (2016) does not have regulations that can be generalized and applied to all vessels, instead individual assessments and risk analysis are performed and referred to as "Approval in Principle". In the future Lloyd´s may develop standardized regulations, but at the moment this is not feasible due to the rapid development of LIB technology.

5.3 Reliability and validity

The background data that was gathered through published sources and literature accessed in Chalmers University of Technology´s databases is viewed reliable. Some data used originated from sources that have a commercial interest in battery technology but were considered reliable because of their prominent role in their respective fields.

Because battery hybrid technology is still new and being developed continually, all installations of these types of systems are unique. This prompted the researchers to focus on one specific installation.

Stena Lines vessel Stena Jutlandica was chosen because of its proximity to Chalmers University of Technology campus and because of Stena Lines role as a major operator of RoPax ferry's in Sweden. That Stena Line also had close ties to Chalmers and that the project had been co-funded by the Swedish Transport Agency and European Union ensured that the researchers could expect transparency during data collection.

The number of respondents is somewhat limited but is the opinion of the researchers that there are obvious similarities in how the engineering officers responded during the interviews. This in turn makes the researchers to conclude that these results with high probability reflect the opinions of all engineers working onboard Stena Jutlandica thus insuring the validity of the research. The researchers further believe that the results gathered during the study can be generalized with high reliability to RoPax vessels that are converted close to the point in time when this article was written. Further development of these technologies and regulations associated with them can afflict how the engineering officers view similar installations in the future. Limited availability of studies with similar research topics has restricted the researcher's ability to compare with results of other researchers to judge the reliability of their own results.

6 Conclusion

Through reviewing relevant literature and interpreting information attained during interviews the following conclusions were deducted.

- The primary benefits of operating with a battery hybrid auxiliary system according to engineers are blackout prevention, reduced maintenance and lower fuel consumption.
- The primary disadvantages of operating with a battery hybrid auxiliary system are risk of a lithium-ion fire and advanced systems with a high learning curve.
- The effects on the emergency organization by the application of the hybrid auxiliary system consist of training and educating the crew in appropriate measures when dealing with a battery fire. Further impacts on the emergency organization were limited as a result of any potential fire would be suppressed with fixed firefighting systems.

6.1 Future research

Since this research was limited to a single vessel it could be of interest to furthered research how the installation affected other engineering officers on other vessels with a similar engine arrangement. Further studies could also be conducted on other vessel types such as anchor handlers. The research could also be expanded to review how deck officers are affected by the installation of a hybrid auxiliary system. A similar study could also be performed on the same vessel in few years to assert that the system still functions and to review if any new guidelines have been implemented by the classification society.

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Appendix 1

Frågeformulär till bakgrundsintervju:

- Vad har du för tjänst och hur är denna kopplad till hybriddrift av en RoPax färja?
- Hur länge har du haft denna befattning?
- Har du någon tidigare erfarenhet av liknande system?

- Hur såg el systemet ut innan konverteringen?
- Hur såg el systemet ut efter konverteringen?
- Vad har batterierna för kapacitet?
- Hur ser strömförbrukningen ut ombord?
- Vad fick er att implementera batterihybriddrift på Jutlandica?
- Hur finansierades projektet?
- Vad är den förväntade livslängden på batterierna och hur lönsam beräknar ni att denna installation kommer att bli?
- Utfördes någon riskanalys av installationen?
- Vilka säkerhetsåtgärder implementerades vid konverteringen (brand, utrymningsvägar m.fl.)?
- Räknade ni med några miljövinster från installationen?
- Finns det möjlighet att få ritningar på hur elsystemet såg ut innan och efter konverteringen?
- Hur många arbetar ni i maskinavdelningen?
- Hur många av dessa är maskinbefäl?

Appendix 2

Frågeformulär till primärintervju

- Vad har du för tjänst ombord?
- Hur är denna kopplad till hybriddrift av en RoPax färja?
- Hur länge har du haft denna befattning?
- Har du någon tidigare erfarenhet av liknande system?
- Har du tjänstgjort ombord både före och efter konverteringen?

- Hur används dieselgeneratorerna och batteriet under en typisk överfart med Jutlandica?
- Hur kördes diselgeneratorerna på en typisk överfart innan konverteringen?
- Hur användes diselgeneratorerna på en typisk in och utkörning innan konverteringen?
- Hur körs dieselgeneratorerna och batteriet vid en typisk in och överfart efter konverteringen?
- Hur har underhållsarbetet påverkats av konverteringen?
- Hur har du i din befattning och yrkesroll påverkats av batteriinstallationen?
- Har man sparat in driftstimmar på dieselgeneratorerna genom denna konvertering?
- Hur har konverteringen påverkat säkerhetsorganisationen ombord?
- Har säkerhetsrutinerna för din tjänst blivit påverkade av konverteringen?
- Känner du dig tryggare i din yrkesroll jämfört med före konverteringen?
- Vad anser du är dom största fördelarna med installationen?
- Vad anser du är dom största utmaningarna med installationen?
- Finns det något annat du skulle vilja förmedla som kan vara intresse för vårat arbete?