BACHELOR THESIS – ME 141502

THE TECHNICAL AND BUSINESS ANALYSIS OF USING SHORE POWER CONNECTION IN THE PORT OF HAMBURG

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2016

SKRIPSI – ME 141502

ANALISA TEKNIS DAN BISNIS PENGGUNAAN KONEKSI DAYA PANTAI DI PELABUHAN HAMBURG

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TEKNIK SISTEM PERKAPALAN
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APPROVAL FORM

THE TECHNICAL AND BUSINESS ANALYSIS
OF USING SHORE POWER CONNECTION
IN THE PORT OF HAMBURG

BACHELOR THESIS

Submitted to Comply One of The Requirements to Obtain a
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on
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SURABAYA
JULY, 2016

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APPROVAL SHEET

THE TECHNICAL AND BUSINESS ANALYSIS OF USING SHORE CONNECTION IN THE PORT OF HAMBURG

FINAL PROJECT

Submitted to Comply One of The Requirements to Obtain a Bachelor Engineering Degree

On

Laboratory of *Marine Electrical and Automation System* (MEAS)

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Department	:	Marine Engineering

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ASSIGNMENT OF BACHELOR THESIS

Hochschule Wismar,
University of Applied Sciences Technology, Business and Design
Department of Maritime Studies

Warnemünde, November 24th 2015

Assignment for Bachelor Thesis

Student : Devi Hotnauli Samosir

Subject : The technical and business analysis of using shore power connection in the Port of Hamburg

Supervising Professor	:	Prof. Dr.-Ing.Markert	Hochschule Wismar
Assistant Supervisor	:	Dr.-Ing. Wolfgang Busse	Hochschule Wismar

Date of issue: November 24th 2015
Filing date: June 17th 2016

Task

The operation of the vessels with electric shore power during stays in port gets increasingly important for both economic and environmental reasons. In US ports this is now mandatory and accordingly ships must be equipped with shore power equipment. The aim of the thesis should be to develop a decision-making tool for the use of shore-side electricity in the port of Hamburg, based on the analysis of the technical and business aspects.

The following aspects should be considered in particular:

1. Analysis of the harbor-side costs and conditions for connection and use of electric shore power.
2. Analysis of the on-board costs and conditions for connection and use of electric shore power.
3. Analysis of the regulatory requirements for the use of electric shore power.
4. Analysis of the technical conditions and facilities for the connection of the electric shore power.
5. Development of a decision support for the electric shore power based on a software that considers the various factors.

The supervising Professor reserves the right to widen or narrow down the scope of the task as he sees fit while it is being processed. Contacts with other institutions and companies may only be established in agreement with the supervisors. The publication of the work or parts of it requires prior permission of the supervisors. The work shall be prepared in accordance with the applicable guidelines of Hochschule Wismar for academic and scientific work. At least two consultations with the supervising professor are required as part of the processing.
The final version of the thesis is to be submitted in a generally accepted electronic format (such as PDF or similar) and in four printed copies at the Organization Office in Rostock-Warnemünde, Germany.

Prof. Dr.-Ing. M. Markert

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THE TECHNICAL AND BUSINESS ANALYSIS OF USING SHORE POWER CONNECTION IN THE PORT OF HAMBURG

Name : Devi Hotnauli Samosir
NRP : 4212101022
Department : Marine Engineering
Supervisors : Dr.-Ing. Wolfgang Busse

ABSTRACT

In port, when the ship is berthing the loading, unloading, and hospitality activity is using auxiliary engine. The combustion of marine fuels is a major contributor to air pollution, the air pollution is released 400 km around the port area. The impacts of the pollution are respiratory, health, and the environment around ports. Study indicates 60.000 of cardiopulmonary mortalities caused by ship air emission. Ship emission represents 3% of global CO_2, 15% of global NO_x, and 6% of global SO_x emission. Because of that Hamburg Port is released the shore power facilities in July 2015 with idea of smart port and use the renewable energy such as wind turbine and solar panel compliance with IEC-ISO-IEEE 8005-1. In this bachelor thesis, the cost and also the condition between shore power and auxiliary engine will be analyzed and compared to find the most economical between shore power facilities and ship's auxiliary engine. Shore power facilities in Hamburg are provided by SIEMENS with SIHARBOR and use a robot arm by Stemman Technik as the cable management system. The goal of this thesis is developed calculation tool to see the cost comparison and also the emission.

And from the calculation tool the shore power is reducing the emission by 100% because of using the renewable energy and become economical than using auxiliary engine, it can save up to €1000. The other benefits are ship owner can save maintenance of their auxiliary engine and also saved the file. It shows that the shore power is a proven technology to reduce the emission and saved berth cost.

Keywords : High Voltage Shore Connection, onshore power , Port of Hamburg

ANALISA TEKNIS DAN BISNIS KONEKSI SHORE POWER DI PELABUHAN HAMBURG

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ABSTRAK

Di pelabuhan, saat kapal tersebut berlabuh loading, unloading, dan aktivitas perhotelan adalah menggunakan mesin kapal. Pembakaran bahan bakar laut adalah penyumbang utama polusi udara, polusi udara dilepaskan 400 km di sekitar area pelabuhan. Dampak pencemaran adalah gangguan pernapasan, kesehatan, dan lingkungan sekitar pelabuhan. Studi menunjukkan 60.000 dari kematian cardiopulmonary disebabkan oleh emisi kapal udara. Emisi kapal mewakili 3% dari CO2 global, 15% dari NOx global, dan 6% dari emisi global SOx. Karena itu Pelabuhan Hamburg membuat fasilitas daya pantai pada bulan Juli 2015 dengan ide *smart port* dan menggunakan energi terbarukan seperti turbin angin dan menggunakan regulasi Internasional IEC-ISO-IEEE 8005-1. Dalam tesis ini, biaya dan juga kondisi antara daya pantai dan mesin kapal akan dianalisa dan dibandingkan untuk menemukan yang paling ekonomis antara fasilitas daya pantai dan mesin kapal. Shore fasilitas listrik di Hamburg disediakan oleh SIEMENS dengan SIHARBOR dan menggunakan lengan robot oleh Stemman Technik sebagai sistem manajemen kabel. Tujuan dari tesis ini ialah mengembangkan alat perhitungan untuk melihat perbandingan biaya dan juga emisi.

Dan dari alat perhitungan *shore connection* dapat mengurangi emisi sebesar 100% karena menggunakan energi terbarukan dan menjadi ekonomis daripada menggunakan mesin kapal, karena menghemat biaya hingga 1.000 €. Manfaat lainnya adalah pemilik kapal dapat menghemat pemeliharaan mesin bantu mereka. Ini menunjukkan bahwa daya pantai adalah teknologi yang terbukti untuk mengurangi emisi dan biaya sandar kapal.

Kata kunci: Pelabuhan Hamburg , Shore Connection, Tegangan Tinggi Shore

PREFACE

First of all, I am grateful to the God for the good health and well being that were necessary to complete this bachelor thesis. I wish to express my sincere thanks to my supervisor Prof. Dr.-Ing Markert and Dr.-Ing. Wolfgang Busse, for gave me a lot of guidance, knowledge, advice, and opportunity. I would like to thank to all people who have helped me in this thesis : Mr. Jens Borchhardt who introduce me to Mr. Volker Stutz as a data provider from Carnival Maritime representative of AIDAsol, and also thanks to Mr. Thomas Kopel data providers from Siemens and Mr.Florian Garmann from Stemman Technik. Without their passionate participation the data could not have been successfully conducted.

I am also grateful to Capt. Onasis Muskita, my supervisor in CNOOC who support me to take this bachelor thesis in Rostock Germany Further, I would also like to acknowledge Ir. Dwi Priyanta MSE. as my lecture who always gives a lot of guidance and advice from the beginning of the semester. My friends : Hafidh, Adrian, Herlan, Dhaifina, Fitrani, Egi, Cynthia,Yohana, Christo and all my friends at Marine Engineering Department ITS who always helped and gave motivation to me. I also place on record, my sense of gratitude to one and all, who directly or indirectly, have let their hand in this venture.

Finally, I must express my very profound gratitude to my parents, my sisters: Sabrina, Hillary, Natalia, all of my family, and Frans Dwiko for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you

Rostock, June 2016

Devi Hotnauli Samosir

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List of Abbreviations

Abbreviations	Meaning
AE	Auxiliary Engine
IMO	International Maritime Organization
MARPOL	Marine Pollution Prevention
EU	European Union
ETS	Emission Trading System
SSE	Shore Side Electricity
IGBT	Insulated Gate Biopolar Transistor
AMP	Alternative Maritime Power Supply
ISO	International Organization for Standardization
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
HVSC	High Voltage Shore Connections
HV	High Voltage
FO	Fiber Optic
ECGS	Exhaust Gas Cleaning Systems
MGO	Marine Gas Oil
HFO	Heavy Fuel Oil
OPS	Onshore Power Supply
LNG	Liquefied Natural Gas
ESI	Environmental Ship Index
LSMGO	Low Sulfur Marine Gas Oil
WPCI	World Ports Climate Initiative
SOLAS	Safety of Life at Sea
M2C	Modular Multilevel Converter
HMI	Human Machine Interface System
SIPLINK	Siemens Multifunctional Power Link

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CHAPTER I
INTRODUCTION

1.1 BACKGROUND

In a port, when the ship is berthed, the operation for loading, unloading and hospitality activities are using the ship Auxiliary Engines (AE) to generate electrical power. The emission caused by the Auxiliary Engine of the ship is released within 400 km of land. One ship pollutes as much as 50 million cars annually. The impact of air emissions from ship Auxiliary Engine are respiratory problems, health, environment, and people around ports. Studies indicate 60.000 of cardiopulmonary mortalities due to ship emissions. [1]

In US Ports the ships mandatory must be equipped with shore power equipment. The operation of the vessel with electric shore power during stays in port gets increasingly important for both economic and environmental reasons. Shore power connection is a proven technology which provides many benefits besides eliminates all gaseous pollution from a vessel which burning diesel fuel while in port, reduce low frequency vibrations and noise, improving working conditions in ports, facilitating maintenance and repairs on Auxiliary Engines while not in operation, and reducing each pollutant by about 90% and offer a low cost when the ship is berthed in Port.

Nowadays, in Germany there are two ports that provide shore power connection facilities, that is Lübeck Port and Hamburg Port. The port of Hamburg just released the shore power facilities in July 2015 for the cruise ship to minimize a major source of air pollutant in the port area and make a clean energy supply.

In this bachelor thesis will be discussed about the economical comparison between shore power connection with diesel fuel. And the result of this bachelor thesis is a decision making tool to choose the most economical between shore power connection with diesel fuel, and analyze the environmental benefit of shore power connection in Port of Hamburg.

1.2 STATEMENT OF PROBLEM

Ship traditionally not subject to emissions control, when the ship is berthed in port, the ships use their Auxiliary Engines (AE) to generate electrical power for loading unloading and hospitality activities (i.e. lights, air-conditioning, the galleys, etc.). Ship emissions are one of the largest uncontrolled sources of pollutants.

Table 0-1.SO_x and NO_x emissions in MARPOL Annex VI

<table>
<tr><th rowspan="3">Year</th><th colspan="2">SO_x limit in fuel (% m/m)</th><th>Average NO_x limit in fuel (g/kWh)</th></tr>
<tr><th colspan="2">MARPOL Annex VI</th><th>MARPOL Annex VI</th></tr>
<tr><th>High sea and berth</th><th>SECA</th><th>High sea and berth</th></tr>
<tr><td>2009</td><td rowspan="4">4.5%</td><td rowspan="2">1.5%</td><td rowspan="3">11.8</td></tr>
<tr><td>2010</td></tr>
<tr><td>2010, July</td><td rowspan="3">1.0%</td></tr>
<tr><td>2011</td><td rowspan="3">9.6</td></tr>
<tr><td>2012</td><td rowspan="3">3.5%</td></tr>
<tr><td>2015</td><td rowspan="3">0.1%</td></tr>
<tr><td>2016</td><td rowspan="2">2.3</td></tr>
<tr><td>2020</td><td>0.5%</td></tr>
</table>

SECA: currently the Baltic Sea, the North Sea, and the English Channel

Source : (Radu and Grandidier 2012)

As a consequence, International Maritime Organization (IMO) was set-up the new environmental regulations at a global scale. In 2004, The MARPOL Convention (73/78), focused on minimizing pollution by ships and applies equally to every member state worldwide. Annex VI has placed limits on sulfur oxide (requiring use of <4.5% sulfur fuel by 2010, and its target is to reduce world maritime sulfur output to <0.5% by 2020) and nitrogen oxide emissions from ship exhaust and prohibited deliberate emissions of ozone. In addition to Port State Control, there are additional controls and penalties to ensure the compliance of the international standards.[2]

Table 0-2. MARPOL 73/78 annex VI / 2010 control and penalties

	Controls	Penalties	Advertisements	Admonishments (with/without fine)
Hamburg	291	125	14	35/53
Bremen	405	37	9	35/0
Niedersachsen	1.145	8	2	2/0
Schleswig-Holstein	1.102	45	21	18/6
Mecklenburg-Vorpommern	306	2	0	1/1
Gesamt	3.249	217	46	91/60

Source :(Clean North Sea Shipping 2014)

In Europe, where SO_2 emissions have shown a decreasing trend for 25 years, the emissions from ships are particularly important. In the year 2000 emissions from international shipping in the seas surrounding the European Union (EU) between 20%-30% of the land based emissions, while in 2020 emissions from maritime activities are projected to be about as large as those from land-based sources.[3] In 2010, shipping accounted for 15,3% of the EU’s transport greenhouse gas emissions. A recent report showed that ships arriving at or departing from EU ports emitted 180 million tons of CO_2 in 2010, which was 4% of the EU’s total emissions.[4]

The problem of using diesel fuel is increasing carbon and nitrogen dioxide emissions. There are many opinions about using this cold ironing system in the ship company based on the diesel fuel price and the difference of berth cost using the shore power connection or diesel fuel.

In this bachelor thesis, will be analyzed any gaps between the shore power connection and diesel fuel located in the port of Hamburg, so they can know deficiencies and could be determined what is the economical between those elements.

Based the description above delivered two main issues, they are:

1. Is it economically feasible to get a shore power connection compared with diesel generated powered by the ship self?
2. What is the environmental benefit for the port of Hamburg and surrounding areas when the ship changes its energy supply from diesel generator power on-board to sustainable energy supply from the shore?

Constraints:

1. The economic analysis between MGO with shore power connection
2. Voyage reports provide exact data on loading and refueling
3. This research only in Hamburg port with shore power connection facility

1.3 STUDY LITERATURE

1.3.1 Potential Shore Power in Europe

In US ports this is now mandatory and accordingly ships must be equipped with shore power equipment. The results of the evaluation of the theoretical maximum potential of Shore Side Electricity SSE in terms of GWh for the year 2020 are presented in Fig. 1 .If all seagoing ships in European harbors would use SSE by 2020 for covering their energy demand at berth, they would consume 3342 GWh annually (or 3543 GWh if we also consider inland shipping), which is approximately 0.1% of the electricity consumption in Europe as a whole in 2012. Fig. 1 also denotes the excessive energy demand of cruise ships while staying in-port due to their hospitality activities, as their annual electricity consumption in ports (i.e. 1334 GWh) represents 39.9% of the total. The energy requirements in terms of annual electricity consumption (GWh/a) for EU seaports in 2010 and 2020 have been estimated based on detailed analysis of the traffic in each port, and results are depicted in Fig. 2. The inland ports are not plotted because of their very low impact on the results (they potentially contribute to 6% of the total demand from SSE). As can be seen, similar geographical patterns appear between 2010 and 2020 with small anticipated increase in some areas.[5]

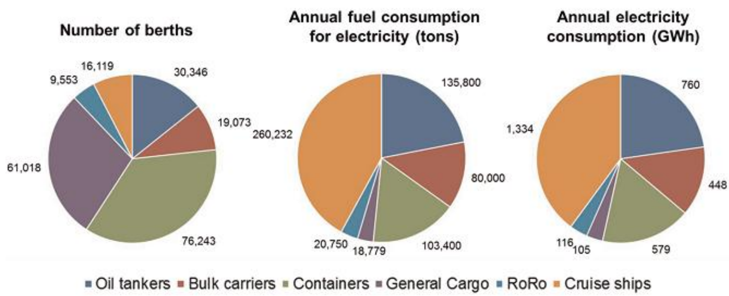

Figure 0-1.Maximum potential of SSE of ships at berth in EU ports for year 2020.

Source : (R.Winkel, et al. 2015)

1.3.2 Shore Power Supply

Shore power supply or cold ironing is a process enabling a ship to turn off its engines while berthed and to plug into an onshore power source. The ship’s power load is transferred to the shore-side power supply without a disruption of onboard services,but it is possible to have a disruption when the transfer is blackout . This process allows emergency equipment, refrigeration, cooling, heating, lighting, and other equipment to receive continuous electrical power while the ship loads or unloads its cargo. Cold Ironing is also known as shore Connection, On Shore Power Supply, High Voltage Shore Connection (HVSC).

The concept of *plugging in* a ship at port allows to shutting down diesel generators which can eliminate pollution from shipboard emissions. The source for shore power supply is provided by: grid power from an electric utility company, in port power plants, renewable energy resources ,and also an external remote generator.

1.3.3 Shore Power Benefits

- **Social benefits (health impacts)**

Shore Side Electricity (SSE) is an option to reduce emissions from the ships while in the port. The extent of the reduction depends mainly on the one hand, on the type of fuel burned in the ship (HFO or Diesel) as reference value and on the other hand the energy mix used for the electricity generation on shore. Hall indicates, for example for the UK a reduction of emissions of CO_2 (25%), SO_2 (46%), CO (76%) and NO_x (92%) when using SSE as opposed to onboard power generation. Hall used IEA databases to the electricity supply and atmospheric emissions to compute the mass of emissions, which would be released if ships obtain electrical power from national electricity grids and compared the results to the existing emissions from ships at berth reported in the literature.[6]

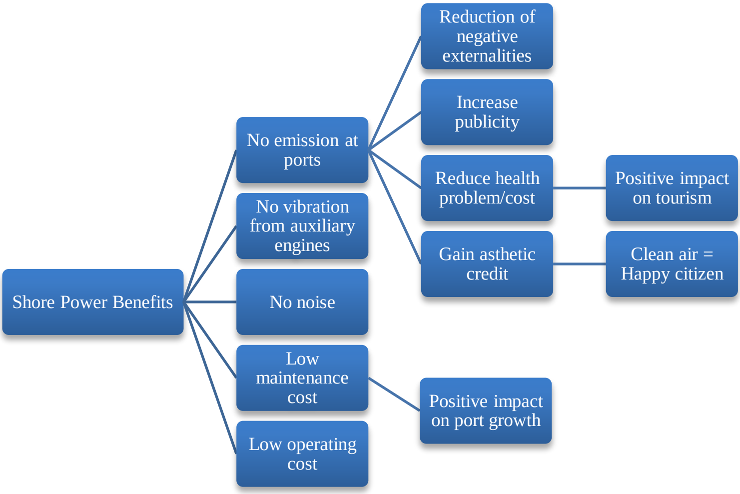

Figure 0-2.Shore Power Benefits

Source: Adapted from Altran 2008, p. 5. Tool Kit (Shore Power).

- **<u>Ships benefits</u>**

Use of shore power facilitates maintenance of the ship's engines and generators, and reduces noise. As a result crew on board is exposed to less noise and emissions on deck, the engine room environment is quiet at all port calls, and stevedores are exposed to fewer emissions from the ship. The total noise generated from the ship is normally significantly lower with the ship’s auxiliaries shut down, although this depends on the characteristics of each specific vessel. [7]

1.3.4 Shore Power Disadvantages/Limitations

- Considerable capital investment must be made in land-based power supply utilities.

- The international ISO standard for High Voltage Shore Connections (HVSC) was adopted in 2012, so the first international standard for OPS systems, called IEC/ISO/IEEE 80005-1 Utility connections in port
- Few cruise vessels are equipped with cold-ironing technology and 90% of those that are equipped with such technology use 60Hz

1.3.5 Marine Diesel Fuel

Marine diesel fuel is at the bottom of refinery process, and therefore rich in sulfur but low in price[8]. IMO requires to use fuels with a sulfur level no more than 35,000 parts per million (ppm) and after 2020 the sulfur level of marine diesel < 5,000 ppm. The emissions intensity from marine diesel engines is pretty high. Therefore shore power supply offer a better solution for reducing the emission.

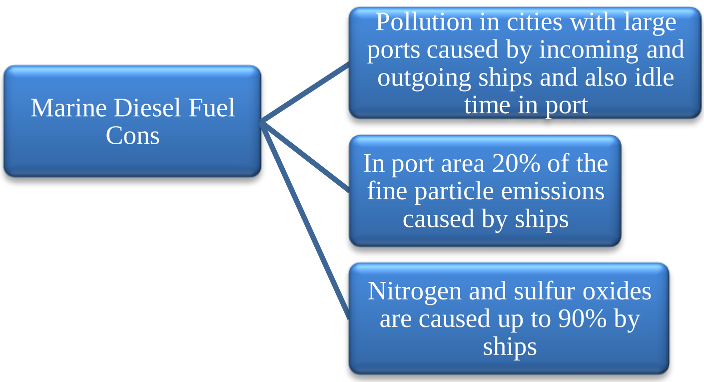

Figure 0-3.Marine Diesel Fuel Disadvantages
Source : ABB

1.3.6 SWOT Shore Power

The use of shore power like all other technologies has its own strengths, weaknesses, opportunity and threats. These factors have been a subject of discussion dominating the various arguments on its adoption or otherwise as a cost-effective means of reducing ship board emissions in port.

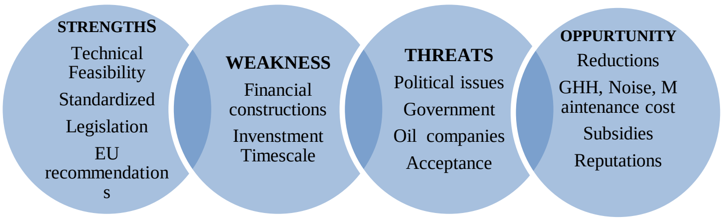

Figure 0-4.SWOT of Shore Side Electricity

Source: (Altran 2008)

1.3.7 Port using Shore-side Power Supply

OPS systems have been developed in North America as well as Europe for seagoing ships. The following table illustrates the developments of high voltage OPS installations in ports worldwide.

Year of introduction	Port name	Country	Capacity (MW)	Frequency (Hz)	Voltage (kV)	Ship types making use of OPS
2000-2010	Gothenburg	Sweden	1.25-2.5	50 & 60	6.6 & 11	RoRo, ROPAX
2000	Zeebrugge	Belgium	1.25	50	6.6	RoRo
2001	Juneau	U.S.A.	7-9	60	6.6 & 11	cruise
2004	Los Angeles	U.S.A.	7.5-60	60	6.6	container, cruise
2004	Piteå	Sweden	1.0	50	6	RoRo
2005-2006	Seattle	U.S.A.	12.8	60	6.6 & 11	cruise
2006	Kemi	Finland		50	6.6	ROPAX
2006	Kotka	Finland		50	6.6	ROPAX
2006	Oulu	Finland		50	6.6	ROPAX
2008	Antwerp	Belgium	0.8	50 & 60	6.6	container
2008	Lübeck	Germany	2.2	50	6	ROPAX
2009	Vancouver	Canada	16	60	6.6 & 11	cruise
2010	San Diego	U.S.A.	16	60	6.6 & 11	cruise
2010	San Francisco	U.S.A.	16	60	6.6 & 11	cruise
2010	Karlskrona	Sweden	2.5	50	11	ROPAX
2011	Long Beach	U.S.A.	16	60	6.6 & 11	container
2011	Oslo	Norway	4.5	50	11	cruise
2011	Prince Rupert	Canada	7.5	60	6.6	
2012	Rotterdam	Netherlands	2.8	60	11	ROPAX
2012	Ystad	Sweden	6.25	50 & 60	11	ROPAX
2013	Trelleborg	Sweden	3.5-4.6	50	11	ROPAX
2015	Hamburg	Germany	12	50&60	6.6&11	cruise

Figure 0-5. Ports using Shore Power Supply

Source: (World Ports Climate Initiative n.d.)

From data above we can analyze port of Hamburg which types of ship using shore power supply is cruise ship. And make a decision tool to another types of ship as container and RoRo

1.4 OBJECTIVE

This bachelor thesis aims to:

1. To evaluate the environmental impacts of ships
2. To compare and analyze the economical ways between diesel fuel and shore power
3. Cost effectiveness analysis for shipping companies or ship owner
4. Costanalysisforport
5. To simulate an economic ways between diesel fuel and shore power
6. To develop a decision making tool for the use of shore side electricity in the port of Hamburg.

1.5 BENEFITS OF BACHELOR THESIS

The benefits that can be obtained from this bachelor thesis are:

1. To find a more environmentally friendly way to operate it
2. To make a decision making tool which can use in every type of ship to choose shore power or auxiliary diesel engine
3. Ship owners can choose the cheapest one between shore power and diesel fuel
4. To decrease its energy consumption cost
5. To make a green ports concept

1.6 METHODOLOGY

To solve the problem above, the five stages are divided as work processes for data collection and analysis, namely:

1. Statement of Problem

This bachelor thesis begins by identifying the problems regarding to the case study in Hamburg Port with two conditions, shore power connection and auxiliary diesel engine.

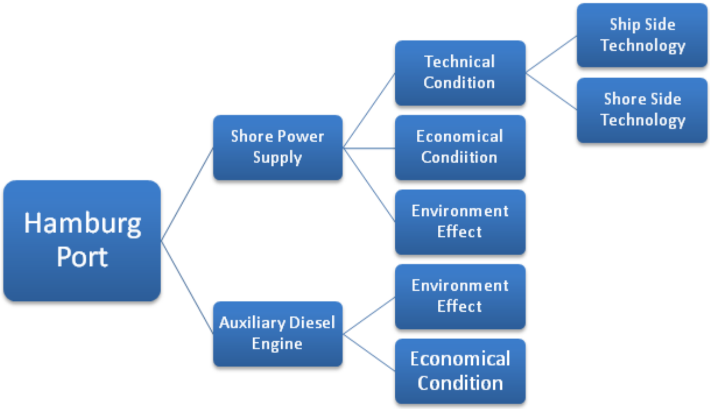

Figure 0-6.Study Case in Hamburg Port

2. Literature Study

This process covers the writer to gather a brief knowledge and information shore power, diesel fuel, the price of MGO the technical requirement of ship power and diesel fuel.

Literatures required for this stage are:

Technical of shore power system and basic theory

- Port of Hamburg condition
- Ship emission
- Diesel fuel price
- HV plants of the vessel

3. Data Collection in Hamburg Port

In this process, accurate and valid data on port conditions are collected based on real time in the port.

Data required for this stage are:

- Traffic and activity statistic of the ships
- Existing shore power connection
- Contract
- Price
- Capacity
- Technology
- Port infrastructure
- Real cost of the electricity / day
- Pollution data
- Regulatory of Hamburg Port
- Cost of fuel and lube price

4. Analysis and identify the economical difference

Analyze the data of the shore power connection and identify the economical factor and environmental factor.

Table 0-3. Identify economical factor

Ship's name	Times of berth	Berth Time (hours)	Electrical Power Demand (kWh / day)	Price
-	-	-	-	-

Table 0-4. Identify Environmental Effect

Auxiliary Diesel Engine	Shore Power Connection
-	-

Table 0-5. Source emission of shore power connection

%	Sources	Pollution Unit
-	-	-
TOTAL EMISSION		

5. Decision Making Tool

The decision making tool is a calculation to choose the most economical way between shore power connection and auxiliary diesel engine using Microsoft-Excel.

-Onshore power **-On board power**

Table 0-6. Shore Power Cost & Onboard Cost

OPERATIONAL COSTS	
INPUT	COSTS (€)
Electricity price (€/ kWh)	
Tax (€/ kWh)	
Consumption (kW)	
TOTAL COSTS (€)	

OPERATIONAL COSTS	
INPUT	COSTS (€)
Diesel (USD/ton)	
Consumption (ton/h)	
Emission Penalty	
TOTAL COSTS (€)	

Table 0-7 Shore Power Supply Pollution Indicator

POLLUTION		
INPUT		POLLUTION UNITS
SOURCE	(i.e coal , wind , water)	
Pollutants	**Emissions**	**Pollution Units**
CO2	-	-
NOx	-	-
PM	-	-
SO2	-	-
	TOTAL	

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CHAPTER II

ANALYSIS OF THE HARBOUR-SIDE COSTS AND CONDITIONS FOR CONNECTION AND USE OF ELECTRIC SHORE POWER

2.1. Port of Hamburg

As the second busiest port in Europe, Port of Hamburg make a challenges to produce a clean air, reduce noise, and keep the air emissions. Because of that they established smart-PORT energy on July 2015. Port of Hamburg has Shore Power Facilities and LNG Power Barge. The plant in Altona is an important element in order to achieve tangible results in Hamburg's air quality.

Figure 0-1 Electric shore power at the cruise terminal Altona

Source :
http://www.bpoports.com/OPS_Seminar/Lebmeier.pdf

The cruise terminal Altona is starting operations in 2011, and it is capable for cruise vessels with maximum length 300 m and maximum draught 10.5 m. [9]

Shore power facilities in Altona Terminal are using a renewable energy to reduce emissions effectively such as wind power plants, solar power, and biomass. The first European shore power facilities have a capacity of 12 HVA and works with a patented, mobile robot arm designed by Stemmann Technik). It is suitable for 50 Hz with 6 kV or 10 kV and 60 Hz with 6.6 kV or 11 kV.[10]

There also LNG power barge in Hafencity Terminal by Becker Marine System for the energy saving and emission reducing supply of power to cruise ships during berthing at Hamburg. Classified as a seagoing ship, the LNG Barge is 76 m long, 11.4 m wide, and has a 2.5 m draught. It is equipped with modular silently operating 7.5 MW LNG generator set power plants fuelled by two 17 ton LNG containers. The main concept of the LNG Barge is using Liquefied natural gas (LNG) to generate energy in combined heat and power units and generators aboard the floating LNG HYBRID Barge. Then the electricity will be fed into the cruise ship's power supply. LNG is a clean energy because it reduce 20% of CO_2, low NO_x, no SO_x and all particular matters

.

Figure 0-2 LNG Hybrid in Hafen Terminal

2.2. Harbor-side Costs

Hamburg port authority has released the port fees and charge 2016 which divide into some price category. The table below shows a summarize of cruise ship price in port in various factors. (For price details, see Annex 1)

Table 0-1 Port fees and charges

Port Fees and Charges		
Name	**Price**	**Details**
Berth fees	0,2384 € / GT	Port fees cover a period up to 120 hours
Low season discount	50%	October-November / January-March
ESI discount		See ESI score discount at http://www.environmentalshipindex.org/Public/Ships
ESI score 20 - 25	0,5%	Maximally € 250
ESI score 25 - 35	1%	Maximally € 500
ESI score 35 - 50	5%	Maximally € 1000
ESI score ≥ 50	10%	Maximally € 1500
Port power discount	15%	Maximally € 2000

Table 0-2 Shore power fees and maintenance

Shore Power Fees and Maintenance	
MAINTENANCE	
Onshore power supply	20.000€/year
FEES	
Environmental tax	-
Fees for electric power source(€/KWh)	0,0005 € / kWh
Incentives for using shore power	15%

2.3. Harbor-side Conditions for Connection

Shore side requirement for connection according to IEC 61936-1 are: *(See 4.2)*

- System component
  - Circuit breaker, disconnector, earthing
  - Transformer
  - Neutral earthing resistor
  - Equipment earthing conductor bonding
- Electrical protection system
- HV interlocking facilities: HV plug/socket outlets, operating the HV circuit breaker, disconnector and earthing switch
- Converter equipment : Degree of protection, cooling, protection

\Harbor-side condition is when the power in the feeding bus bar, operator have to make the shore cable earthed and interlocked for safe cable connection. After connection the ship requires the shore to supply the power and the ship is switching and synchronizing. Synchronization from shore can be applied when the cable is energized from the ship, the onshore power is energized too. Then onshore power will checks voltages both from ship and shore and adjust the shore voltage to ship's voltage. Later onshore power will closes circuit breaker and gives signals that ship diesel generator can be shut down and run parallel with onshore power in a short time.

2.4. The Use of Harbor-side Electric Shore Power

Table 2-3 shows the total pollution when using shore power and using onboard power. The HPA is declaring that the electricity source is from renewable sources (wind and solar panel) which reduced the NO_x, SO_x, CO^2, and PM. Even the ship is already using LSMGO with sulfur < 0,1% the emission is still exist.

Table 0-3 Air pollution at Port while using shore power vs ship's engine

POLLUTION USING SHORE POWER			
Electricity source	: wind , solar panel		
Pollutants	Emmisions(ton)	Pollution units	TOTAL
CO^2	0		0
N0x	0	0	
SO2	0	0	
PM	0	0	
POLLUTION USING ONBOARD POWER			
Electricity source	: LS MGO (0,1%)		
Pollutants	Emmisions(ton)	Pollution units	TOTAL
CO^2	37,26		1.090
N0x	0,7506	750,6	
SO2	0,02376	304,128	
PM	0,0162	35,64	

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CHAPTER III
ANALYSIS OF THE ON-BOARD COSTS AND CONDITIONS FOR CONNECTION AND USE OF ELECTRIC SHORE POWER

3.1. AIDA

AIDA cruise ships spend almost 40% low-sulphur fuel of their operating time in port [11]. Because of that in port must have a power supply to ensure onboard operation, because it is an environmentally friendly option. In July 2013, AIDAsol became the first ship of the fleet to be completely equipped for shore-side power and can receive it in any location that offers.[11] There are nine cruise vessels have a diesel-electric propulsion system except AIDAcara which use only diesel, it is means that the propulsion is done by separate diesel engines which are directly connected to the propeller drive. All other nine vessels are have only diesel for power generation and electric motors for propulsion.[11] Ship diesel engines will operate power generators, and fed into onboard grid, so only as much energy as is required is generated, and AIDA cruise ships are highly efficient at all sailing speeds.[11]

Figure 0-1 AIDA Fleet

Source: https://www.aida.de/en/aida-cruises/company/fact-and figures/fleet.23923.html

Table 0-1 AIDA ship-specific data

AIDA Fleet						
Name	**Length (m)**	**Voltage (kV)**	**Frequency (Hz)**	**GT**	**Drive**	**Electrical Power**
AIDAsol	253.33	11 kV	60 Hz	71304 GT	Diesel electric	36000 kW
AIDAcara	193.34	690 V	60 Hz	38557 GT	Diesel mechanically	21720 kW
AIDAvita	202.85	6.6 kV	60 Hz	42289 GT	Diesel electric	27550 kW
AIDAaura	202.85	6.6 kV	60 Hz	42289 GT	Diesel electric	27550 kW
AIDAdiva	251.89	11 kV	60 Hz	69203 GT	Diesel electric	36000 kW
AIDAbella	251.89	11 kV	60 Hz	69203 GT	Diesel electric	36000 kW
AIDAluna	251.89	11 kV	60 Hz	69203 GT	Diesel electric	36000 kW
AIDAblu	253.33	11 kV	60 Hz	71304 GT	Diesel electric	36000 kW
AIDAmar	253.33	11 kV	60 Hz	71304 GT	Diesel electric	36000 kW
AIDAstella	253.33	11 kV	60 Hz	71304 GT	Diesel electric	36000 kW

3.2. On-board Costs

AIDA was one of participating ship list in WPCI, the AIDA ESI score is 21.5 to calculate the ESI

The formula for the ESI Score is:

$$\frac{2 \times ESI\ NO_X + ESI\ SO_X + ESI\ CO_2 + OPS}{3.1}$$

Where:

- ESI NO_X represents the sub-points for NO_X and ranges from 0 to 100 sub-points
- ESI SO_X represents the sub-points for SO_X and ranges from 0 to 100 sub-points
- ESI CO_2 is the bonus for reporting on two data sets of EEOI and is fixed at 10 sub-points
- OPS is the bonus for the presence of an OPS* on board irrespective of its use and is fixed at 35 sub-points

So the AIDA ESI score is:

ESI Details for ship: 9316139

IMO Number: **9316139**
ESI NO_X Score: **33.4**
ESI SO_X Score: **0**
ESI CO_2 Score: **0**
ESI OPS Score: **0**
ESI Total: $\frac{\text{ESI } NO_X(33.4 * 2) + \text{ESI } SO_X\ 0 + \text{ESI } CO_2\ 0 + \text{ESI OPS } 0}{3.1}$ = **21.5**

ESI Score Valid From 01 April 2016 until 30 September 2016

Because AIDA participating in WPCI, the vessel will get an extra discount while berthing (See APPENDIX 1) with ESI score 20 up to < 25 = 0.5% discount, maximally €250. When AIDA use shore power there will be a discount incentive 15% with a maximal €2000. Table below will give a comparison when the vessel is not using the shore power. It makes a difference in the amount of €1268

Table 0-2 AIDAsol port fees using shore power

Input Data			Port fees	
AIDAsol	71304	GT	16998	€
Tariff	0,2384	€/GT		
call in November	50%	low season discount	8499	€
			8499	€
ESI score 21.5	0,5%	environmental discount	42	€
			8456	€
Using shore power	15%	port power discount	1268	€
Port fees payable after discount			7188	€

Table 0-3 AIDAsol port fees without shore power

Input Data			Port fees	
AIDAsol	7130 4	GT	1699 8	€
Tariff	0,238 4	€/GT		
call in November	50%	low season discount	8499	€
			8499	€
ESI score 21.5	0,5%	environmental discount	42	€
	Port fees payable after discount		8456	€

3.3. On-board Conditions for Connection

3.3.1. Ship requirements for connection

Cruise ship must install some equipment to make a connection to shore power supply as a transformer, cable connectors, short circuit protection, alarm, etc.

The main ship requirements from IEC /ISO/IEEE 80005-1 : *(see Chapter 4.4)*

- Shore connection switchboard
- Circuit breaker, disconnector, earth switch
- Transformer
- Protection against electrical faults
- Ship connection procedure
- Ship power restoration
- Load transfer

Time needed for installing the shore power to the ship is approximately 45 minutes. First to make a connection the ship shore connection has to be earthed and interlocked to make sure the safe cable connection. Then robot arm will connect the cable connection of HV-power cable and FO-cable. After connection the ship requires the shore to supply the power and the the ship is switching and synchronizing. The synchronization from ship will begin after all the onboard equipment is energized from the shore power except the synchronization switch, and when it is done the synchronization switch will close and shore power run in parallel with ship generator only for a short time. The diesel generator will unload, stop running and the generator switched off automatically.

3.3.2. System voltage and frequency

Most cruises with length ≥200 meters operate with high voltage due to high power demand and use of diesel electric propulsion. System frequency which operates in cruises with length ≥200 meters are 60 Hz. (ABB)

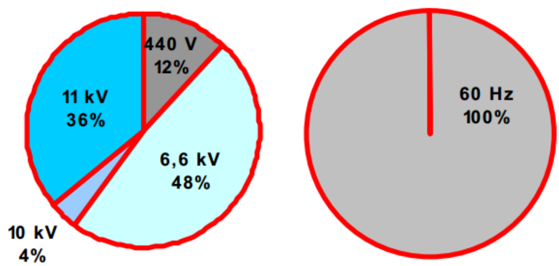


Figure 0-2 Main system voltage and frequency for cruise ≥200 meters

Source: ABB

3.4. The Use of On-board Electric Shore Power

AIDAsol is recently berth 10 hours per-day with an average power demand 4.66 MW (See Figure 3.4-1). The minimum power is 3,05 MW and the highest power that received is 5,19 MW. When using the shore power the shore connection room will be locked due to safety regulation, if the door is open the shore connection will shut down automatically, cut the powers and ship will black out.

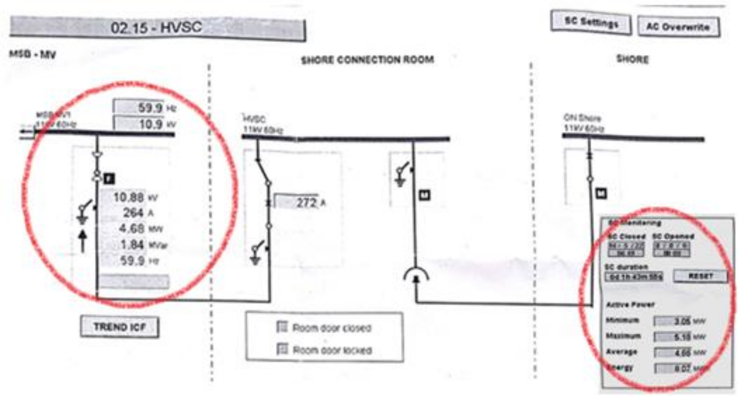


Figure 0-3Power demand of AIDAsol while berthing

CHAPTER IV
ANALYSIS OF THE REGULATORY REQUIREMENTS FOR THE USE OF ELECTRIC SHORE POWER

The shore power facilities which created by Siemens use the international standards of IEC/ISO/IEEE 80005-1 (medium voltage side).

4.1. IEC/ISO/IEEE 80005-1

The IEC/ISO/IEEE 80005 describes HVSC systems, on board the ship and on shore, to supply the ship with electrical power from shore. A typical HVSC system described in this standard consists of hardware components as shown in Figure.1

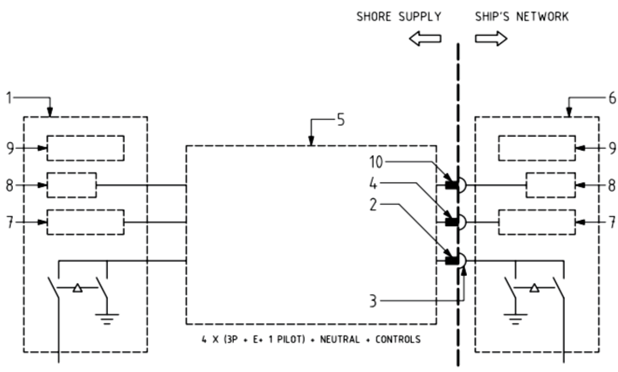


Figure 0-1 Block diagram of HVSC system arrangement on cruise ship

Source : ISO/IEC/IEEE 80005-1

1. A shore connection system can be supplied from national grid or port electrical system through a power frequency conversion
2. HV-plug as a connector that inserted into the ship’s HV socket
3. Ship’s HV-socket as a connecting point which drove the power towards the ship’s network
4. Pilot wires which integrated with plug and socket to control the system
5. The cable management system as a connector to feed the power from shore to shore connection switchboard
6. The shore connection switchboard is provided with a shore power connecting circuit breaker with circuit protection devices
7. Interlocks with pilot wire as a prevention of such disturbances
8. Communication for control and monitoring
9. Protective relaying to detect unbalance phase conductors, directional earth fault, current balance between cables in parallel
10. Communication and control wires

4.1.1. Electrical requirements

The HVSC must be rated for at least 16 HVA , nominal system voltage 11 kV or 6.6 kV. Consideration given to HVSC system with lower rank where only ships with lower power demands will be required to connect so ship with higher power demands will reduce their power before connecting. Prospective short-circuit level of contribution from the edge of HV distribution system should be limited to, shore side system 25 kA rms. Prospective short-circuit level of contribution from ship running induction motors and generator in operation will limited to short circuit current of 25 kA rms for 1 s.

4.1.2. Quality of HV Shore Supply

The HV shore supply system shall have an acceptable voltage variation at ship switchboards between no-load and nominal rating. The compatibility assessment shall include verification of the following:

a) Voltage and frequency tolerances (continuous):
   1) The frequency shall not exceed the continuous tolerance ±5% between no-load and nominal rating
   2) For no-load conditions, the voltage at the point of the shore supply connection shall not exceed a voltage increase of 6% of nominal voltage
   3) For rated load conditions, the voltage at the point of the shore supply connection shall not exceed a voltage drop of -3,5% of nominal voltage

b) Voltage and frequency transients:
   1) The response of the voltage and frequency at the shore connection when subjected to an appropriate range of step changes in load shall be defined and documented for each HV shore supply installation
   2) The maximum step change in load expected when connected to a HV shore supply shall be defined and documented for each ship

3) Comparison of 1) and 2) shall be done to verify that the voltage transients limits of voltage +20% and -15% and the frequency transients limits of ±10% will not be exceeded.

c) Harmonic distortion

- For no load conditions, voltage harmonic distortion limits shall not exceed 3% for individual harmonic 5% for total harmonic distortion

4.2. Shore Side Installation

The shore side installation shall be accordance with IEC 61936-1, where the installations and equipment is capable of persisting electrical, mechanical, climatic and also can anticipate environmental effect.

4.2.1. System Components Requirements

- Circuit-breaker, disconnector and earthing switch

Circuit breaker shall be released automatically when there is a faulted of a network after an interval time, which permits it to recover from temporary fault.

The disconnectors and earthing switch must be secure from any operation by tension or pressure for manual operation

Earthing switch is a connection of each earthing device to the terminal intended to be connected to earthing system of installation. The earthing switches must provide a device to indicate the contact position of interrupting or isolating.

- Transformer

Transformers shall be a separate type of rolls for primary and secondary side. The secondary side shall be a star-configuration with neutral bushings (Dyn). The temperature of the supply transformer windings will be monitored, if there is an over temperature alarm signal will be activated and transmitted to ships by communication data links to warn the crew. Short circuit protection for supply transformer must provided circuit breaker or fuses on main and secondary circuit breaker.

- Neutral earthing resistor

Neutral point of transformer feeding shore-to-ship power will be earthed by a neutral earthing resistor. Neutral earthing resistor in amperes, not to be ≤ 1,25 times the system charging current initial. The rating will be at least 25. An Earth fault will not make one step or touch voltages exceeding 30 V in any location. The sides of the transformer will be earthed neutral earthing resistor, through 540 ohms constantly and only attached to the side of the ship.

- Equipment earthing conductor bonding

The system earthing conductor will connect to a system earthing electrode, the additional system bonding conductor will connect the neutral earthing resistor to the earthing bus of the main shore power switchboard. Equipment of earthing conductors terminated shore power outlet box receptacles will be connected to ship and proceed to make an equipotential bond between shore and ship.

4.2.2. Shore to Ship Electrical Protection System

The HV circuit breaker on secondary side of transformer will open all isolated poles in the following circumstances:

- Over-current including short-circuit
- Over voltage / under voltage
- Reverse power

To meet this requirement, the following protective devices or the equivalent of protective measures will be given:

- Synchrocheck or voltage sensing device
- Under voltage
- Reverse power
- Load balance, negative phase sequence over-current
- Instantaneous over-current
- Phase time over-current
- Earth fault, over-current
- Overvoltage
- Directional phase current

4.2.3. HV Interlocking

While plugging and unplugging HV plug and socket-outlet connections, operating personnel shall be protected from electrical hazard by an interlocking arrangement. Operational procedures and interlocking to verify that non-fixed high voltage cables are discharged before disconnection.

- Handling of HV plug or socket outlets

Handling HV plug/socket outlets are only allowed when corresponding earthing switches on both ship and shore side was closed.

- Operating of HV circuit breakers, disconnectors and earthing switches

Arrangements should be provided so circuit, disconnect or circuit breaker is not closed when the condition exists:

- One of the earthing switches is closed (shore-side / ship-side)
- Pilot contact circuit is not established

- Emergency stop facilities are activated
- Ship or shore control, alarm or safety system self-monitoring diagnostics detect an error that would affect safe connection
- The communication link between shore and ship is not operational
- The permission from ship is not activated
- HV supply is not present
- Equipotential bonding is not established

4.2.4. Shore Connection Converter Equipment

The considerations are the effect of harmonic distortion and power factor that required for power rating. The use of frequency converter will not reduce the selectivity of the largest on-board load while connected.

- Degree of protection

From IEC 61936-2 the degree of protection IP2X compliant in mandatory minimum. IP2X is the IP code necessary to prevent access to hazardous parts with fingers and protect the equipment inside the enclosure against ingress of solid foreign objects having diameter of 12.5 mm and greater [12]. The degree of protection against the entry of dust and water objects will be selected in accordance with the special environmental and climatic conditions at the installation location. Dangerous parts of the machine will be protected against accidental contact by person.

- Cooling

Where is forced or closed cooling circuit is used, either by air or with liquid, the alarm will start when the cooling media temperature exceeds a predetermined or flow limit. Semiconductor devices converter will be arranged that it can't keep it loaded unless effective cooling is maintained. In addition, the load can be automatically reduced to a level compatible with the cooling available. Liquid cooled converters equipment will be provided with leakage alarm to prevent the failure of electrical equipment. Where the liquid-cooled-heat exchanger used in transformer cooling circuit, there will be detection of leaks and the cooling system must be arranged so that the entry of cooling liquid into the transformer is prevented

- Protection

In case of overload, the alarm signal is activated to warn the crews. The alarm will be activated at a level lower than the excess protection circuit breaker

4.3. Ship to Shore Connection

A ship to shore connection cable installation will be set up to provide adequate movement compensation, cable guidance, and positioning of cable during normal planned. The shore-side will be fitted with a plug if a socket outlet will be used on shore, and ship-side will be fitted with a connector, if an inlet will be used on-board. Cable extensions will not be permitted.

4.3.1. Cable management system

The cable management system will be able to move the ship to shore connection cable, allowing the cable to reach the socket-outlet and inlet. It is able to maintain the optimum length of cable which minimize slack cable and prevent the tension limits exceeded. Equipped with a device which can monitor the maximum cable tension. Positioned to prevent interface with ships berthing and mooring systems, including a system of ships that are not connected to shore power while berthing. Keep the bending radius of cables above the minimum bending radius. It's also capable of supporting cables over the entire range of ship draught and tidal ranges. And capable of taking and saving the cable once operations are complete.

- Monitoring of cable tension

The cable management system does not allow tension cables exceed the allowed values of the design. The means to detect the maximum tension cable will be provided or where an active cable management system that limits the cable tension is provided to detect a lack of available cable length will be provided with threshold limits given in two stages:

1. Alarm
2. Activation of emergency shut down facilities

- Monitoring of cable length

The cable management system will enable the cable to follow the movement of the ship during the entire range of ship draught and tidal ranges. Where the cable length may vary, the remaining cable length will be monitored ant threshold is set in two phases:

1. Alarm
2. Activation of emergency shut down facilities

- Connection conductor current unbalance protection

The sip and shore HV circuit breaker will be arranged to open all insulated poles in the event of current imbalances damaging among several phase conductor. The following protective devices, or equivalent protection should be provided:

- Current balance between cable in parallel
- Directional earth fault

- Equipotential bond monitoring

The equipotential bond created by the ship to shore connection cables shall be constantly monitored. The scheme will also be self monitoring. It should be installed on the shore/board where the cable management system is installed.

- Slip ring units

Slip ring units shall be tested according to IEC 62271-200 to:

- HV test
- Impulse voltage withstand test
- Insulation resistance measurement
- Heat run test with nominal current
- Short circuit withstand test
- Arc test, if accessible under energized conditions
- IP rating

4.3.2. Plugs and socket outlets

Plug and socket will be equipped with a mechanical-securing devices that locks connection in the engaged position. It should be designed for made a correct connection. Socket outlets and inlets will be interrelated with earth switch so it cannot be inserted without earthing switch in the closed position, which means the handling is only when the earth switch is closed.

Contact sequence must be in the following order:

- Connection and Disconnection
  - Earth contact: bring current capacity will be at least equal to the current rated of the other contacts
  - Power contact

- Pilot contact : will open before the needed degree of protection is no longer reaches for the removal of HV-plug or connector.

4.3.3. Interlocking of earthing switches

Contact power HV still be earthed up until all connections are made and the pilot circuit is closed, emergency stop switch no activated, communication link between shore and ship operators, ship or shore control, alarm or security system self-monitoring detects no failure will affect the safety of connection , and permission from ship and shore is activated.

4.3.4. Ship to shore connection cable

Cable types at least flame-retardant type, the outer sheath will be oil-resistant and resistant to sea air, sea water, solar radiation (UV) and shall be non-hygroscopic. The temperature shall be at least 90°C insulation. The correction factor air is above 45°C. The maximum operating temperature must not exceed 95°C.

Equation 4.3.4-1 Rated voltage

The standard rated voltages U_0/U (U_m) of the cables considered are as follows:

$$U_0/U\ (U_m) = 6/10\ (12)\ \text{kV r.m.s}$$

The standard rated voltages U_0/U (U_m) of the neutral cables considered are as follows:

$$U_0/U\ (U_m) = 1{,}8/3\ (3{,}6)\ \text{kV r.m.s}$$

Where:

U_0 is the rated voltage between phase conductor and earth or metallic screen for which the cable is designed;

U is the rated frequency voltage between phase conductors for which the cable is designed;

U_m is the maximum value of the highest system voltage which may be sustained under normal operating conditions at any time and at any point in the system. It excludes transient voltage conditions and rapid disconnection of loads.

Source : (IEC/ISO/IEEE 8005-1 2012)

4.3.5. Storage

The arrangement shall be provided for storage when not in uses such as:

- Ship board equipment is stored in dry spaces
- Shore based equipment shall comply with national standards
- Removable equipment shall be stowed, stored, and removed without damage
- Equipment does not present a hazard during normal ship operation
- During storage, the plugs, socket-outlets, inlets and connectors shall maintain their IP ratings

4.4. Ship Requirements

The instrumentation will described at all locations where the load transfer and synchronization are performed.

4.4.1. Ship electrical distribution system protection

Ship electrical distribution system protections are as follows:

- Shore-circuit protection

  Where a connection to more than one HV-shore supply, measures must be taken to prevent HV-shore supplies are connected in parallel if maximum prospective short-circuit current is exceeded at point in the installation

- Earth fault protection, monitoring and alarm

  Where the device settings needed to change when connected to a HVSC supply, means that shall provide for personnel to easily change the settings which is clearly indicated in the control station

4.4.2. Shore connection switchboard

The switchboard shall include a circuit breaker to protect the ship electrical equipment downstream. An automatic operated circuit breaker must be provided. The shore connection switchboard will provided by:

- Voltmeter (three phases)
- Short circuit devices (tripping and alarm)
- Over-current devices (tripping and alarm)
- Earth-fault indicator (alarm)
- Unbalanced protection for systems with more than one inlet

4.4.3. On board transformer

When there is a separate winding type of primary and secondary side, the secondary should be star configuration. The neutral point will be connected to the main switch board according to the method for the main distribution system. Galvanic separation between shore and on-board system should be provided. In a transformer may not require if the ship's network is designed for shore supply voltage and neutral point treatment is in accordance with galvanic separation system of the ship is done on shore.

4.4.4. On board receiving switchboard connection point

- Earthing switch

An earthing switch must be installed if the main switchboard rated voltage exceeds 1000 V

- Instrumentation

If the load transfer through parallel connection is selected the instrumentation must be two voltmeters, two frequency meters, one ammeter with a switch so that current in each phase can be read, phase sequence indicator and one synchronizing device.

The switchboard busbars must connected with one voltmeter and one frequency meter, and the others will enable the voltage and frequency of shore connection to be measured.

- Protection

Tripping and alarm criteria for circuit breaker must be installed in:

- Short circuit
- Over-current
- Earth fault
- Over/under voltage
- Reverse powerPhase sequence protection with alarm and interlock

To meet this requirement, the following protective devices or equivalent protective measures must be provided:

- Synchrocheck
- Under-voltage
- Reverse power
- Phase sequence voltage
- Overload
- Instantaneous over-current

- Operation of circuit breaker

Circuit breakers cannot be closed when one of the following condition exists:

- One of earthing switches is closed
- Pilot contact circuit
- Emergency stop facilities are activated

- Ship or shore control, alarm or safety system self-monitoring properties detect an error that would affect the safety of connection
- Data communication link is not operational
- HV supply is not present
- Equipotential bonding is not established
- Earth fault on ship distribution systems is detected

4.4.5. Ship power restoration

When the ship's main source of electrical power is shut down, and the failure of connection of HVSC supply occurred, the shore connection circuit breaker will automatically open an emergency start:

- Starting an emergency electrical power source by providing emergency services equivalent to SOLAS CH II-1/D
- Automatic connection of transition through the resources of electrical power to emergency services
- Starting and connecting the main switchboard of the main sources of electrical power and sequential restart essential services, in the shortest time practicable. This will be automatic in the case of an emergency shutdown activation

Failure include loss of HV power or disconnection may need to consider relaxing the requirements need to be automatically started and ship's electrical power source connected to existing ships constructed. In such cases, alternative measures for the restoration of the strength of the ship is acceptable to relevant authority must be provided.

4.5. Additional Requirement for Cruise Ship

- Shore connection nominal voltage : 11 kV or 6.6 kV
- Shore connection earthing system : LRE with 540 Ohms NGR
- Number of cables to feed the vessel : 4 power cables, neutral distributed to ship
- Location of the cable management system : berth
- Most frequently used earthing system on the ship: high resistance earthing

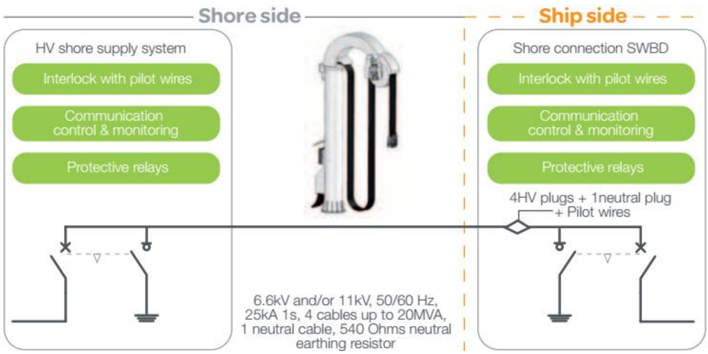


Figure 0-2 Shore connection solution for cruise ship

Source :(Radu und Grandidier, Shore Connection Technology 2012)

CHAPTER V

ANALYSIS OF THE TECHNICAL CONDITIONS AND FACILITIES FOR THE CONNECTION OF THE ELECTRIC SHORE POWER

5.1. SIHARBOR SIEMENS

SIHARBOR is a shore-to-ship connection system developed by SIEMENS that includes all components which is necessary to supply ship from the local grid (see Figure 5.1-1). SIHARBOR in Altona has a 12 HVA –10,0 kV– 60 Hz, which can be transformed to the ship voltage and frequency. There are 4 steps to connect onshore power to the ship, first receive the power, then convert-adapt-separate, supply the power, and distribute on-board the ship. SIHARBOR comprises a variable frequency converter SINAMICS SM120 CM and medium-voltage switchgear NXAir Used that is especially designed for shore connection system. The switch gear offers a long service life of 10,000 cycles of operation for the functions interrupting and earthing .[13]

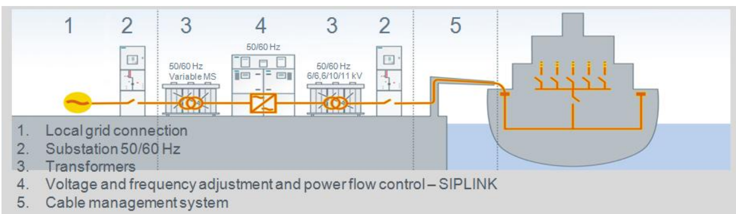


Figure 0-1 SIHARBOR

Source : (SIEMENS n.d.)

5.1.1. SIPLINK as a Medium Voltage DC Link

Siemens Multifunctional Power Link (SIPLINK) is a converter system which based Back-to-back Link (see Figure 5.1-2) and able to control energy flows between sub-networks and improve voltage quality by providing reactive power. SIPLINK provides a means of interlinking different power generators or networks with different frequency or power capacity without impairing system stability or increasing fault currents. Integration of distributed and independent power generator in existing network is also improved which affect to cut investment and life cycle cost.

As a core element for SIHARBOR, SIPLINK can feed on-board system from distribution networks and match various different parameters to one another and interlink them. It consist of two self-commutated IGBT pulse-controlled converters which interconnected through a DC intermediate circuit (see Figure 5.1-3). While converters are connected on one side to the local power supply networks, the other side is connected to the ship's onboard system. After connecting the plug-in connector in the ship, the automation system installed on shore will automatically start. This process is conducted from ship, which make the onboard power supply is not interrupted. SIPLINK is self-synchronizing and takes over the power supply within a few minutes, the diesel generators can then be shut down. To keep a respective protection and avoid galvanic corrosion the electrical is separated between shore-side and on-board network. SIPLINK system is water cooled, the heat exchanger is designed either as an air / water exchange in outdoor installation

Figure 0-2 SIPLINK with open cabinet doors

Source : (SIEMENS n.d.)

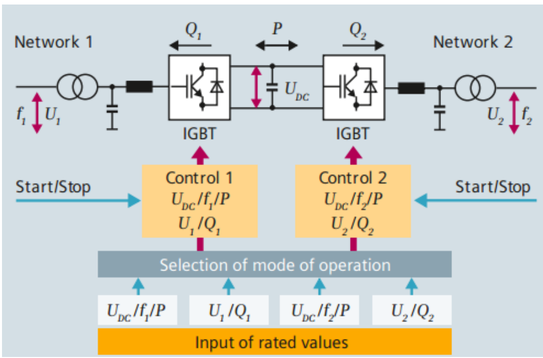


Figure 0-3 System configuration with two self-commutated IGBT pulse

Source : (SIEMENS n.d.)

5.1.1. SINAMICS SM 120 CABINET MODULS

SINAMICS SM 120 CM is a medium voltage converter using M2C (Modular Multilevel Converter) technology, which generates a sinusoidal voltage from the grid. The output current reach a perfect sinusoidal waveform, and filtering is not required. SINAMICS SM 120 CM also has an arc fault tested and has 98.5% efficiency converter. In Figure 5.1.1.-1 there are four types of module:

1. Control Module (CoM)
   As a unit controls and monitors the drive, line and vector control, open loop control / status message / touch panel / bus-interfaces
2. Basic Line Module (BLM)
   As a diode supply for connecting motor modules with power range between 5400-10800 kW
3. Active Line Module (ALM)
   To supply and regenerative feedback unit to feed the connected motor modules with voltage range 3.3-6.6 kV and power range between 6000-12500 kVA
4. Re-cooling Module (RCM)
   To dissipate the power loss about 200 kW from the converter

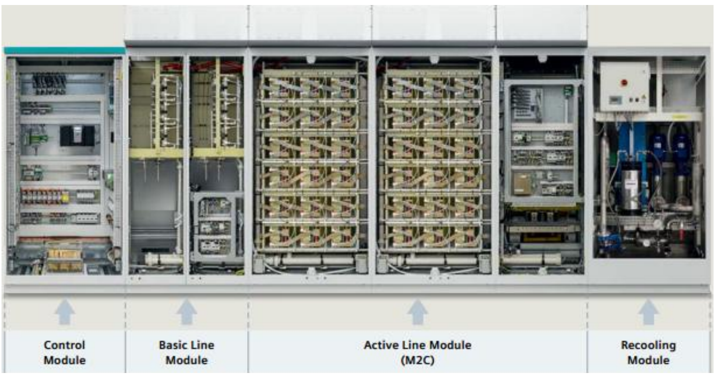


Figure 0-4 SINAMICS SM 120 CM

Source : (SIEMENS n.d.)

Table 0-1 Technical data SINAMICS SM 120 CM

Drive Features	
Output power	4 – 13.3 HVA
Output voltage	ALM 3.3 – 6.6 kV MoM M2C 3.3 – 7.2 kV
Cooling	Water-cooled
Motor type	Induction motors (high speed motors) Synchronous motor for M2C
Input & Output Data	
Input configuration	Active line module : M2C
Input voltage	ALM: 2.3 – 6.6 kV ±10% (M2C)
Input power factor	0.95
Input frequency	50/60 Hz
Output frequency	Up to 150 Hz for M2C
Auxiliary Voltage	230 V 1 AC ±10%, 50/60 Hz ±5% 400 V 3 AC ±10%, 50/60 Hz ±5%
Environmental Features	
Altitude	Up to 1000 m; from 1000 m – 4000 m
Ambient air temperature	+5°C to +45°C
Noise	72 dB – 77 dB
Degree of protection	IP43, IP44

5.1.2. NXAir

NXAIR is a gas-insulated switchgear system that recommended than air-insulated, because of easier maintenance and saving space. NXAIR circuit-breaker switchgear is used in transformers and switching substations. The system is according to IEC 62281-200 or VDE 0671-200 [14]. As insulating medium, air is always available and there is no handling of insulating gas and low/high pressure monitoring required. All switching operations always with high voltage door closed. Feeder earthing switch only operated with switching device in disconnected position. Switching device can only operated in interlocked disconnected or service position. Inside the system there is a coding prevention of switching devices with a lower rated normal current into panels with a higher rated normal current.

voltage	kV	**12**
frequency	Hz	50/60
short-duration power-frequency withstand voltage (phase-to-phase, phase-to-earth)	kV	28 [1]
lightning impulse withstand voltage (phase-to-phase, phase-to-earth)	kV	75
short-circuit breaking current	max. kA	40
short-time withstand current, 3s	max. kA	40
short-circuit making current [2]	max. kA	100/104
peak withstand current [2]	max. kA	100/104
normal current of busbar	max. A	4000
normal current of feeders:		
With circuit-breaker	max. A	4000
With contactor [3]	max. A	400
With disconnector link	max. A	4000
Bus sectionalizer	max. A	4000
Busbar connection panel	max. A	4000

Figure 0-5 NXair as a gas insulated switch gear

Source : (SIEMENS n.d.)

The components in NXAIR are :

1. Vacuum circuit breaker
   The vacuum circuit breaker is suitable for all switching, possible with manual operation and completed by motor operating mechanism. 64 pole low-voltage plug connector between circuit breaker and fixed part.

Figure 0-6 SION vacuum circuit breaker 3AE
Source : (SIEMENS n.d.)

2. Vacuum contactor
   Vacuum contactor is suitable for high switching rates operating. The short circuit protection up to 2 HV HRC fuses connected in parallel. Voltage source is coming from a primary fused control transformer or via external power supply. The pole is same as the vacuum circuit breaker. The contact arms generally with silver plated round contacts.

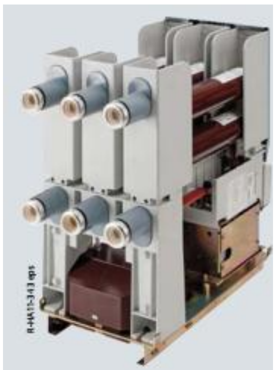


Figure 0-7 Contactor fuse combination 3TL6

Source : (SIEMENS n.d.)

3. Current transformers

   Current transformer using the third principle first is using an inductive block type current transformer principle. With cast-resin insulated, and with coupling electrode for capacitive voltage detecting systems or bushing-type current transformers which is certifiable. The second principle is a low power principle for current measuring, where the cast-resin insulated in same housing block type current transformer, or as ring-core transformer. The constructional principle is by ring core current transformer with integrated precision burden. Transmits primary currents directly proportional to secondary voltages, and also adjusted to numerical protection, control and can measuring relays

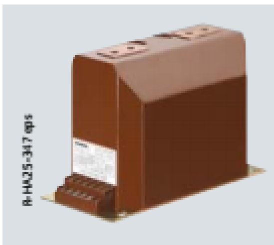


Figure 0-8 Block-type current transformer

Source : (SIEMENS n.d.)

4. Voltage transformers

   Voltage transformers are using two principles, the inductive and low power principle. The inductive principles are cast-resin insulated with single pole/double pole, and have an earth fault winding. The low power principles are integrated in current transformer housing, with resistive voltage divider as a constructional principle. Can adjusted by numerical protection, control and measuring relays.

Figure 0-9 Voltage transformer fixed mounted ; with primary fuse

Source : (SIEMENS n.d.)

5. Low-voltage compartment

   The low voltage compartment is an accommodation of all protection, control, measuring and metering equipment, it is also can be removed as all bus wires and control cables are plugged in. Bus wires are pluggable from panel to panel The low voltage cables are flexible and protected by metal covers.

Figure 0-10 Low voltage compartment

Source : (SIEMENS n.d.)

5.1.3. Stemmann Technik Robot Arm as a Cable Management System

The onshore power supply is using mobile carrier system up to 16 MW, which call a Robot arm. It is an efficient cable handling and connection from Stemmann Technik which can flexibly move from different positions and automatically compensate for tidal range compensation at 9 meters or 29 feet (see Figure 5.1-16). It is easy to control because it is self propelled and a motorized vehicle. The adjustable power voltage is from 6.6 kV – 11 kV. Protection class by IP67. The system is equipped with drive and hydraulic unit, 11 KV connection box, deflection roller, telescopic plug holder system and differential drive. The tidal range can be compensated by a cable loop which are connected full time by stainless steel energy chain to the shore side switch gear without additional plugs and socket (see Figure 5.1-13)

First, to handle the cable the operator will move the robot arm from the garage into ship’s hatch by four wheel drive at a speed of 40m/min. The hydraulic energy for all movements of the robot arm is produced by its own electric motor. When the ship’s hatch is open the robot arm will move the power and communication plugs controlled up to a position which is 200-400 mm in front of the hatch (see Figure 5.1-15) and it's possible to control movable arms in precisely the position to plug holder. Then the telescopig plug holder will connect to ship’s plug one by one by crew ship. After all of the telescopig is connect to the plug ship is ready for synchronization of shore power and ready to receive the power.

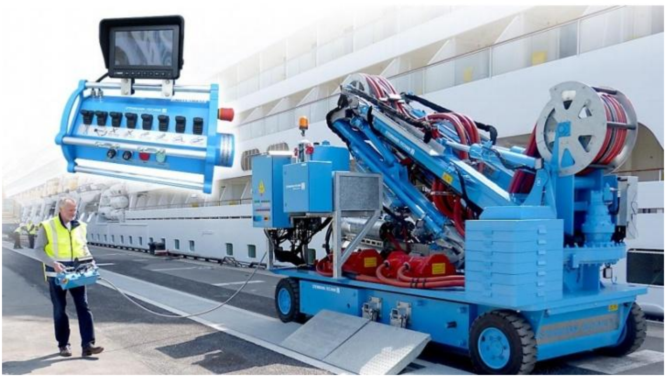


Figure 0-11 Control panel to move the robot arm into ship’s power plug

Source: (Stemmann Technik n.d.)

Figure 0-12 Cable duct and cover lifting device with cable guideway

Source: (Stemmann Technik n.d.)

Figure 0-13 Ship's socket

Source: (Stemmann Technik n.d.)

Figure 0-14 Mechanical connection by telescopig plug holder system

Source: (Stemmann Technik n.d.)

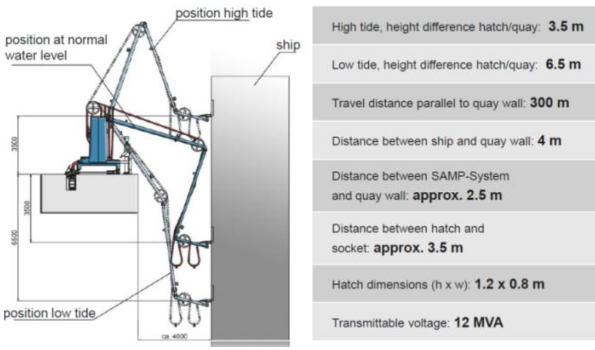


Figure 0-15 Tidal range compensation

Source: (Stemmann Technik n.d.)

5.2. Technical Conditions using PLC SIMATIC S7-300

SIPLINK system equipped with SIMATIC S7-300 as HMI (Human Machine Interface System) that all data can be transferred to control system via bus systems and also displays all operator, control alarm and diagnostic fault data. SIMATIC S-7 steps are divided to eight stages:

1) OFF Position
    - Power on Feeding Bus Bar, and shore cable is earthed an interlocked for safe cable connection
    - Ship shore power connection is earthed and interlocked for safe cable connection
    - Ship is supplied by own generator

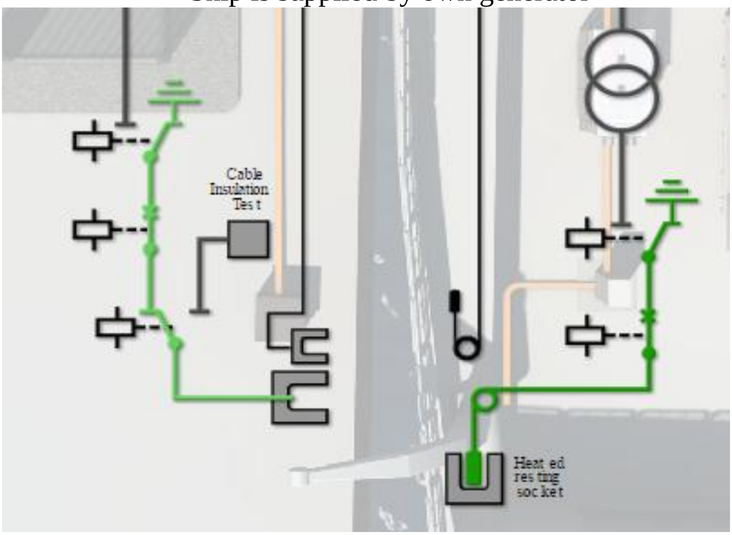


Figure 0-16 Shore cable & ship shore power connection is earthed

Source:(SIEMENS n.d.)

2) Connection

- Manual cable connection of HV-power cable and FO-cable
- Automation systems exchange data and check condition of ship and shore
- Shore automation waits for permission to start up shore power
- Shore power is started from the ship manually and also can be done from shore by ship request

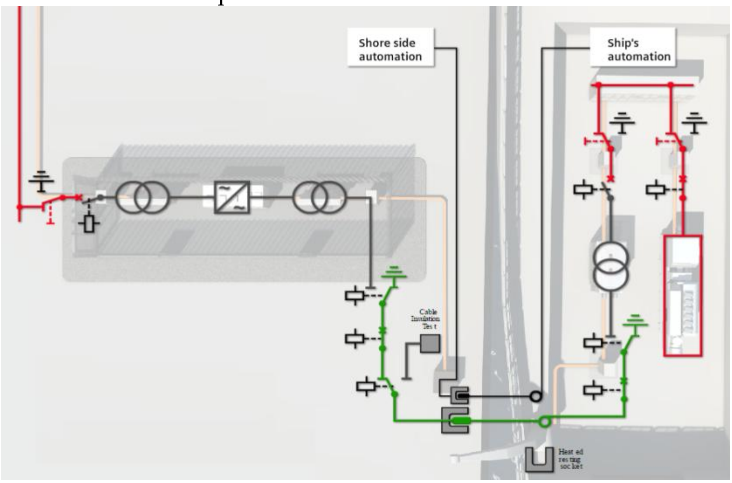


Figure 0-17.Cable connected, Shore power starting, *Source:(SIEMENS n.d.)*

3) Choose Synchronizing

- Synchronizing from shore : cable is energized from ship and also onshore power is energized. Check voltages for both sides, and adjusting the shore voltage to ship's voltage. Closes onshore power circuit breaker and gives signals that diesel generator can be shut down

- Mixed synchronizing : cable is energized from onshore power supply, also ship’s shore power equipment except the synchronizing switch. After synchronizing is done according to the ship's command, the synchronizing switch will close automatically and onshore power will run parallel with a diesel engine in short time
- Synchronizing from ship : cable is energized from onshore power supply, also ship’s shore power equipment except the synchronizing switch. Synchronizing will done automatically/manually and onshore power will run in parallel with a diesel generator

4) ON Position

- Diesel Generators are unloaded and run down in sequence, while Shore Power Connection takes over.
- Diesel Generators are stopped and switched off automatically/ manually
- Ship is safely Powered from Shore Power Connection

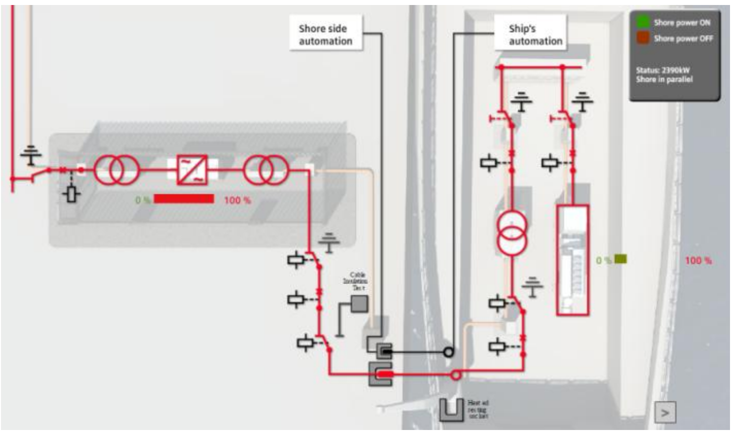


Figure 0-18.Shore in parallel, generator off

Source: (SIEMENS n.d.)

5) Shut Down
    - Ship is safely powered from shore power supply
    - Diesel Generators are started manually and synchronize with on board
    - Generator circuit breaker is closed and shore power supply stopped from ship manually
    - Ship generator runs in parallel to shore power in idle operation
6) Switching OFF
    - Diesel Generators are loaded and take over power while shore power reduces power
    - Shore power runs in idle operation the switches on board are opened
    - Shore power will get signal that switch is open
    - Motor operated switches onshore are opened

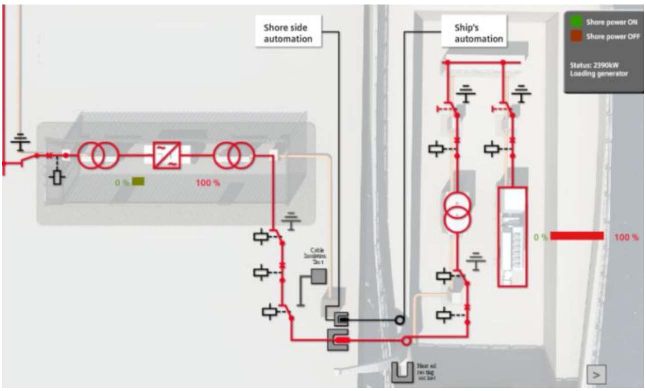


Figure 0-19 Generator started, shore in parallel, loading generator

Source: (SIEMENS n.d.)

7) Disconnection
   - The shore automation system gives signals that breakers are open
   - Motor operated disconnectors switch to earthed position
   - Manual disconnection of HV-power cable and FO-cable
   - Ship sails off

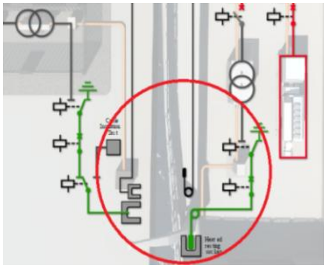


Figure 0-20.Shore power off, shore power earthed

Source: (SIEMENS n.d.)

CHAPTER VI
DEVELOPMENT OF A DECISION SUPPORT FOR THE ELECTRIC SHORE POWER BASED ON MS-EXCEL

6.1. Assumptions

For the purpose of this thesis, the following assumptions were made in calculating the data collected and estimations made:

- Electricity generated from Port of Hamburg is believed to be from environmentally friendly resources such as wind turbine and solar panel
- Only calculate the operational cost to find the cheapest cost between shore power and ship engine
- All ships which use in calculation tools have the shore power facilities on board and ready to connect to shore power
- Cost for electric shore power is 0,5€/MWh (Martechnic Hamburg 2015)
- Cost for lubricating oil is 3500$/ton *(alibaba.com)*
- The port fees are using port price list 2016 , published by the Hamburg Port Authority
- Cost of maintenance €1.6/hour (Jiven, 2004)
- Type of fuel is used LSMGO 0,1% because Hamburg is in ECA area
- Load power for:
    - Cruise : 15%
    - Container: 50%
    - RoRo: 50%
    - Bulk Cargo : 50%
    - Tanker: 60%

6.2. General Formula

The following general formula is used for cost calculation:

Lube cost € =

$$\left(\frac{Power\ Consumption\ (kW)\ \times SLOC\ (\frac{kg}{kWh})}{1000}\right) \times Operation\ time\ (h) \times lube\ price\ (\frac{€}{ton})$$

Fuel cost € =

$$\left(\frac{Power\ Consumption\ (kW)\ \times SFOC\ (\frac{kg}{kWh})}{1000}\right) \times Operation\ time\ (h) \times fuel\ price\ (\frac{€}{ton})$$

Maintenance cost = €1.6/ running hour (Jiven, 2004)

Shore power cost =

$$Consumption\ (kW)\ \times Operation\ time\ (h) \times Electrical\ price(\frac{€}{kWh})$$

Berth cost = See 2.2 ; 3.2 ; Appendix 1

The following general formula is used for emission calculation:

Emission (ton) =

$$\frac{Operation\ time\ (h) \times consumption\ (kW) \times emission\ factor(\frac{g}{kWh})}{1000000}$$

Pollution unit =

$$Emission\ (ton) \times emission\ equivalent\ (\frac{pollution}{kg}) \times 1000$$

Total Cost = SOx pollution unit + NOx pollution unit + PM pollution unit

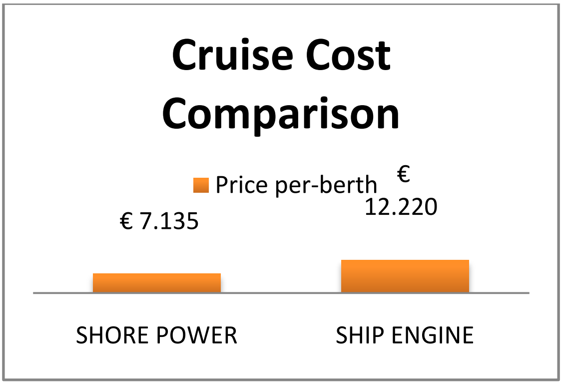
Emission reduction electricity (%) =

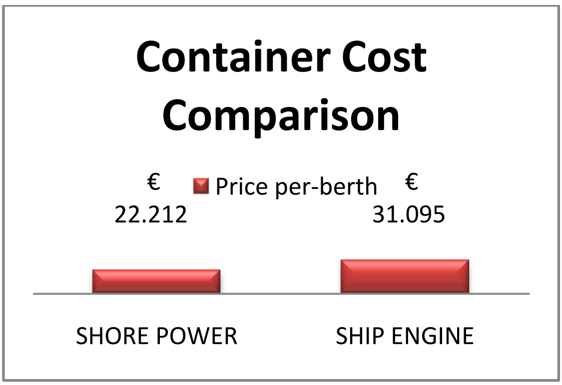
$$1 - (\frac{CO2\ emission\ \ from\ shore\ power}{CO2\ emission\ from\ onboard\ power})$$

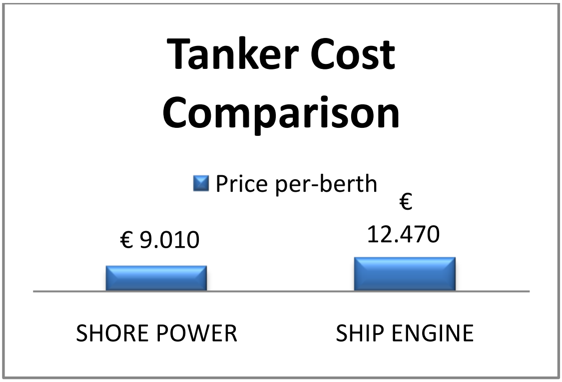
6.3. Cost Comparison Results

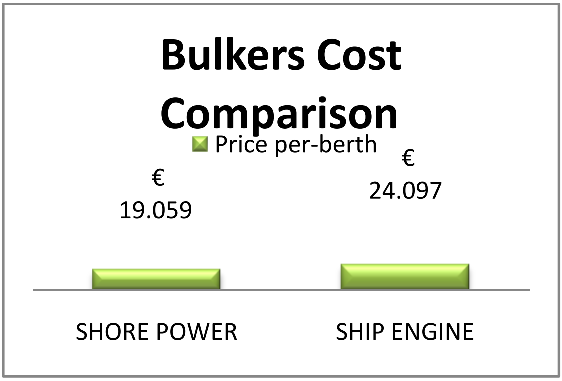
The results from calculation tools shows that using shore power is cheaper than using the ship's engine (see Figure 6-1). Ship owners can reduce the cost from €800 to €9000. When a ship is using shore power, it is also saved the maintenance of the engine. Because the engine will shut down and reduce the maintenance cost.

Table 0-1 Cost comparison of Cruise, Container, Tanker, Bulkers and RoRo






Tanker Cost Comparison
Price per-berth
€ 9.010
€ 12.470
SHORE POWER
SHIP ENGINE


Bulkers Cost Comparison
Price per-berth
€ 19.059
€ 24.097
SHORE POWER
SHIP ENGINE

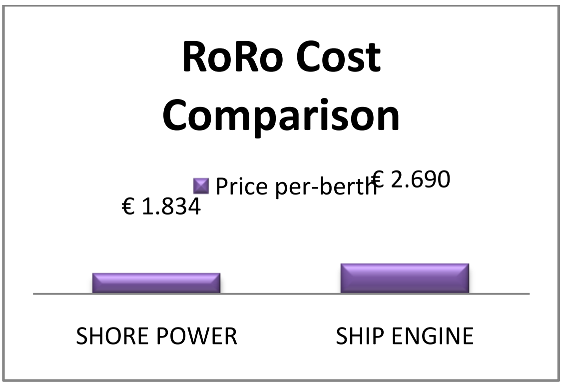

RoRo Cost Comparison
Price per-berth
€ 1.834
€ 2.690
SHORE POWER
SHIP ENGINE

Table 6-2 shows pollution produce by the cruise auxiliary engine using Low Sulfur Marine Gas, Oil with a sulfur content < 0,1%. Total emission which produce is 1.090 kg consist of NOx , SO2 and PM. And table 6-3 shows there are no emission from shore power because of using renewable energy such as wind turbine and solar panel. So the emission reduction electricity is 100% (see Table 0-4) because of using renewable energy.

Table 0-2 Pollution by auxiliary engine

POLLUTION			
Electricity source :	LS MGO (0,1%)		
Pollutants	Emmisions(ton)	Pollution units	TOTAL
CO2	37,26		1.090
N0x	0,7506	750,6	
SO2	0,02376	304,128	
PM	0,0162	35,64	

Table 0-3 Pollution by shore power

POLLUTION			
Electricity source :	wind , solar panel		
Pollutants	Emmisions(ton)	Pollution units	TOTAL
CO2	0		0
N0x	0	0	
SO2	0	0	
PM	0	0	

Table 0-4 Emission reduction electricity

Emission reductions electricity	
NOx	100%
PM	100%
SO2	100%
CO2	100%

CHAPTER VII

CONCLUSION

When the ship is cruising in ECA area they must use fuel oil within 0.1% sulfur content below or have EGCS (Exhaust Gas Cleaning Systems). And the low sulfur fuel is more expensive. Shore power is becoming the best solution to save the operational cost while berthing at port. This thesis analyzes the technical condition of shore power in Terminal Altona, Hamburg which is using the system standards IEC/ISO/IEEE 80005-1. Hamburg is commissioned SIEMENS to build a SIHARBOR which has a capacity of 12 HVA, 11 kV and 60 Hz. And Stemman Technik provides the robot arm as a cable management for connecting the cable from shore to ship and can flexibly move from different positions and automatically compensate for tidal range compensation at 9 meters or 29 feet (see Figure 5.1-16). From the calculation tool which developed in this bachelor thesis, it shows that shore power is way cheaper than an auxiliary diesel engine it can save up to 9000€ with using some limitation (See Table 6-1). The impact when using the auxiliary diesel engine are:

- High emission caused human health impacts
- High cost for fuel
- Need an additional scrubber to reduce emission
- Noise and vibration from engine
- Need an additional cost for engine maintenance
- Climate impact because of air pollution caused by combustion fuel

The benefit when using shore power :

- Cut the emission moreover, while using the renewable source and environmentally friendly (see Table 6-4) which is reducing emission to 100 %.
- Get a 15% discount of using shore power on port fees
- No noise and vibration
- Healthy environment
- Easy to connect due to the technology of robot arm
- Saved maintenance cost for auxiliary engine

From the result of analyzing shore power facility in Hamburg it can be concluded that this facility is not a proven technology because its still need to be improved from the shore side of Altona Terminal. In the other side this facility is using a renewable energy and reduce the total cost when ship is berthed. So the ship owner can choose the shore power facilities as the cheapest than using diesel engines, and port can make a green port concept because using an environmentally friendly electric sources.

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