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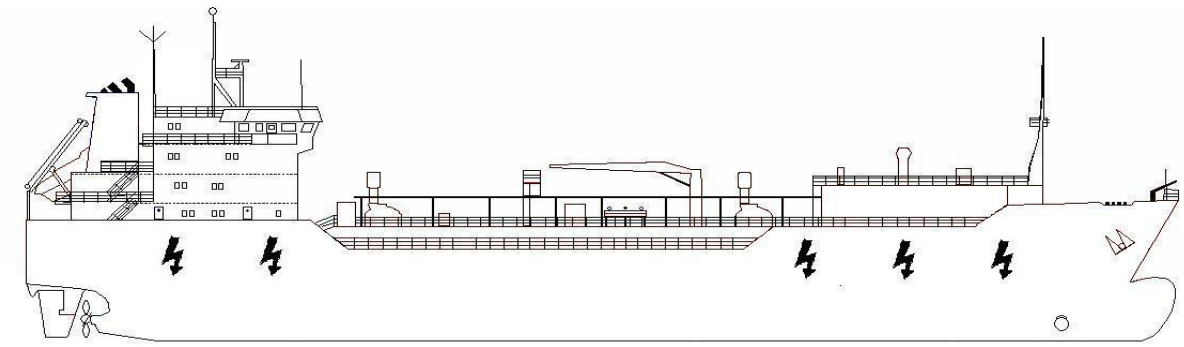
Bulk Electricity Sea Transport from Remotely Located Power Plants

Author: A.G.A. Hammoutene



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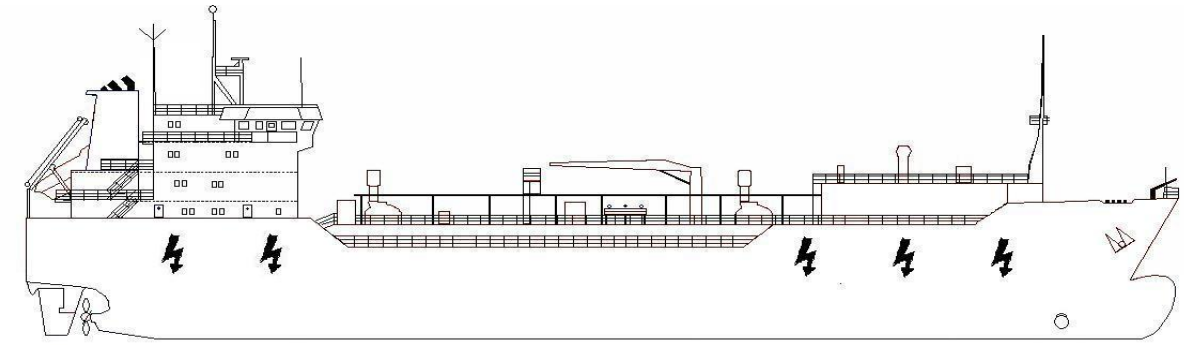

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Preface

Since the beginning of time humankind uses ship transport for the transport of people and goods. Nowadays it is not differently. Today ship transport is indispensable in our modern society. Ship transport is mainly used for the transport of a large variety of cargoes such as ore, rice, grain, containers, chemicals, etc. However, ship transport is not yet used for the bulk electricity transport, despite electricity is one of most utilized energy form in the world. Therefore the goal of the report is to develop and to analyse different electricity transport concepts to achieve bulk electricity transport across the sea in energy efficient and cost efficient manner. Furthermore bulk electricity transport across the sea would enable the transport of renewable energy from remotely located energy sources to electricity consumers. Currently the electricity transport across the sea is only done with submarine electrical power cables. The report is written in a period that the diminishing oil and natural gas resources and the increasing energy demand cause high energy prices. The author hopes that the thesis will provide insight into the different methods to achieve bulk electricity across the sea, so that the energy system becomes more sustainable in the future.

The thesis is written at Delft University of Technology for obtaining a master degree in Naval Architecture. The report has been written under the supervision of ir. J.W. Frouws and prof. ir. A. Aalbers. The author would like to thank ir. J.W. Frouws for his guidance and for improving the thesis. Moreover I am especially indebted to ir. J.W. Frouws for his very valuable criticism on my work. In addition, the author would like to thank prof. ir. A. Aalbers for his patience and the giving opportunity to graduate on this fascinating topic.

My sincere gratitude goes also out to my mother Ria, my brother Lyes, my sister Nadia, Ramdane Hammoutene and my family for their support.

The thesis is dedicated to my father Nazim Hammoutene, deceased on 6 October 2005. His compassion, his strive for perfection and his wisdom were of great value to his family, his friends, his colleagues and the Algerian community in the Netherlands. As person Nazim Hammoutene was very highly esteemed and respected in Algeria, France and the Netherlands.

Delft, Mai 2008

A.G.A. Hammoutene

Summary

Electricity is one of the most utilized energy carriers for energy transmission in the world. In recent years more electricity is generated from renewable energy sources. The main drawback of renewable energy sources is that renewable energy power plants are often connected to certain locations. Sometimes these renewable energy power plants are located in very long distant areas across the sea, so consequently bulk electricity transport to major electric power consuming areas across the sea is not done due to economical difficulties. Therefore the aim of the report is to develop and to analyse different electricity transport concepts to achieve bulk electricity transport across the sea in energy efficient and cost efficient manner. In this case the feasibility of bulk electricity transport between the hydroelectric and geothermal energy sources in Iceland and the electric power consuming areas such as Scotland and European mainland is investigated. During the development of the electricity transport concepts three electricity transport concepts emerged. The three electricity transport concepts are the submarine electric power transmission, the battery ship and the synthetic fuel. In the study the three electricity transport concepts are further developed and analysed. The three electricity transport concepts are analysed by investigating the energetic performance and the cost performance of the three electricity transport concepts for the distances from 0 nautical miles till 6000 nautical miles. In addition the influence of the cost per MWh of power plants on the three electricity transport concepts is examined for the distances of 500 nautical miles and 1000 nautical miles. Currently the electric power transmission with submarine electrical power cables is the only way to deliver electrical energy across the sea. The electric power transmission system is composed of two converter stations and one or two submarine power cables. The other electricity transport concept consists of a battery ship and two small offshore terminals. The battery ship is a 300.000 dwt ship with integrated redox flow batteries. The battery ship is charged and discharged at small offshore terminals. In this report the battery ship is developed till conceptual design.
The last electricity transport concept consists mainly of a production plant for the conversion of electricity into synthetic fuel, a cargo ship and a power plant. In the thesis different synthetic fuels are compared. The different synthetic fuels are hydrogen, ammonia, methanol, ethanol, dimethyl ether (DME), sodium borohydride and zinc. The results of the investigation are that the synthetic fuels hydrogen and ammonia are attractive synthetic fuels for bulk electricity sea transport. Hence follows that the bulk electricity sea transport by means of compressed hydrogen and ammonia is examined in more details and afterwards the two synthetic fuels are compared. The comparison shows that ammonia is a more energy efficient and cost efficient synthetic fuel than hydrogen, so ammonia is the appropriate synthetic fuel for the purpose of bulk electricity sea transport.
Finally, all electricity transport concepts are compared with each other and evaluated.
The main conclusions of the comparison between the electricity transport concepts are:

- The bulk electricity transport with submarine power cable link is the most cost efficient and energy efficient solution till approximately 2500 nautical miles.
- Beyond approximately 2500 nautical miles the bulk electricity sea transport with ammonia fuel is the most attractive solution.
- The submarine power cable link is the most attractive solution for the bulk electricity transport between Iceland and Scotland and the bulk electricity transport between Iceland and European mainland and bulk electricity transports are profitable with the current market prices of electricity in Scotland and European mainland.
- The bulk electricity transport with battery ship could be an attractive solution till approximately 1000 nautical miles, when the costs of batteries are significantly lower.

Table of Contents

1 Introduction

Electricity is one of the most utilized energy carriers for energy transmission in the world. It is a convenient clean flexible energy carrier. Electricity is a convenient energy carrier, because electrical energy can be transformed into mechanical energy, thermal energy, magnetic energy, radiant energy and chemical energy. Besides that the different forms of energy such as mechanical energy, thermal energy, magnetic energy, electromagnetic radiation, chemical energy and nuclear energy are transformed into electrical energy. Electricity has become indispensable for the existence of our modern human society. Electricity enables lighting, entertainment, communication, medical services, computers, internet, medical services, mechanical work, heating and electric vehicles such as train, metro and tram, etc. Summarized electricity is required for operating factories, homes, offices and public transport [43]. The power plants generate electricity from various energy sources such as coal, oil, natural gas, nuclear, waste, wind, hydro, solar, geothermal and biomass.
The electricity from the power plants is transported with transmission lines and distribution systems to the consumer, because electricity is often not produced in the same place that it is consumed. In recent years more electricity is generated from renewable energy sources, because fossil fuels such as coal, oil and natural gas are not sustainable.
The important drawbacks of renewable energy sources are that renewable energy power plants are sometimes connected to certain locations and renewable energy power plants do not often provide for constant energy supply. Moreover the growing world population, the higher living standards and the shortage of fossil fuel resources in the world increase the demand for electricity. Unfortunately, the ‘stranded’ renewable energy sources are often located in very long distant areas across the sea. An example of ‘stranded’ renewable electrical energy sources in a remote long distant area across the sea is the hydroelectric and geothermal energy sources in Iceland. The electricity in Iceland is needed in the electric power consuming areas such as Scotland and European mainland.
However, transporting bulk electricity from remote long distant areas to major electric power consuming areas across the sea is not yet common practice due to economical difficulties. Therefore in this report different bulk electricity transport concepts are developed and investigated to unlock the ‘stranded’ renewable energy sources in very long distant areas across the sea. The goal of the report is to develop and to analyse different bulk electricity transport concepts to achieve bulk electricity transport across the sea in energy efficient and cost efficient manner. The report does not examine the different methods of electric power generation and the grid connection between substation and households. The report consists of 7 chapters. The electricity transport concepts are explored and determined in chapter 2.
The three electricity transport concepts are the submarine electric power transmission, the battery ship and the synthetic fuel. The submarine electric power transmission is described and investigated in chapter 3. The battery ship is developed and investigated in chapter 4. The last electricity transport concept synthetic fuel is investigated in chapter 5. Finally, the electricity transport concepts are compared and evaluated in chapter 6. During the comparison the influence of parameters such as distance and cost per MWh of power plants are determined. In the chapter 7 the conclusions and recommendations are presented.