Transportation Research Part D 51 (2017) 227–239

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Reducing shipboard emissions – Assessment of the role of electrical technologies

Edward A. Sciberras [a,b,*], Bashar Zahawi [b], David J. Atkinson [a]

[a] School of Electrical and Electronic Engineering, Newcastle University, UK

[b] Department of Electrical and Computer Engineering, Khalifa University, Abu Dhabi, United Arab Emirates

ARTICLE INFO

Article history:
Available online 28 January 2017

Keywords:
Auxiliary drives
Energy storage
Batteries
Cold ironing
Onshore power supply
Marine hybrid vessel

ABSTRACT

Saving fuel and reducing emissions are major drivers in the marine industry, with a large number of potential modifications and machinery options available to enable the greening of shipping. Assessing which technology and what combination of solutions gives favourable economic results needs careful consideration of the vessel's operational profile. Electrification of shipboard systems introduces operational flexibility, offering the potential for fuel savings and emission reductions. Auxiliary drives, energy storage and onshore power supply are three approaches which address the issues of ship fuel consumption/emissions, specifically during in-harbour operation of vessels. In this paper, the impact of these three technologies on ship environmental performance and energy consumption is assessed by considering a real case RoRo vessel sailing a real operational profile. Models of the resultant system are built such that the machinery configurations can be analysed separately or in conjunction with each other. The results stress the importance of the operational profile of the vessel, showing significant fuel and emissions reductions during in-harbour operations but relatively small savings when considering operation through a complete return voyage. The sensitivity of the results to fuel and utility costs are also considered and shown to have a large impact on the economic feasibility (or otherwise) of different solutions.

1. Introduction

Environmental concerns play a major role in decision-making processes in all industries. In the marine industry, legislative efforts aim to provide incentives to influence such decisions and reduce the environmental impact of shipping activities. Examples of this include the IMO's ECA Sulphur limits (IMO, 2005), and the European Union's Sulphur directive (The European Parliament and the Council of the European Union, 2012) which both address the Sulphur content of fuel. Compliance with environmental legislation also has monetary benefits in terms of the avoidance of fines and potential savings on fuel costs. The application of these environmentally-friendly solutions however is not a silver bullet, as the result is highly dependent on the actual operational profile of the vessel and its onboard machinery systems. Hence any potential application of a new technology must be comprehensively assessed according to the expected usage and applied in circumstances that fully exploit the benefits of such solutions.

* Corresponding author at: School of Electrical and Electronic Engineering, Merz Court, Newcastle University, Newcastle upon Tyne NE1 7RU, UK.
E-mail address: edward.sciberras@ncl.ac.uk (E.A. Sciberras).

http://dx.doi.org/10.1016/j.trd.2016.10.026
1361-9209/

Nomenclature

CPP	Controllable Pitch Propeller
ECA	Emission Control Area
HFO	Heavy Fuel Oil
LUT	Look Up Table
MGO	Marine Gasoil
OPS	Onshore Power Supply
RoRo	Roll-On Roll-Off

Most vessels nowadays use diesel engines for propulsion as well as auxiliary power generation (Argyros et al., 2014). These typically run on Heavy Fuel Oil (HFO) for economic reasons. This fuel, however, is not the cleanest in terms of emissions and diesel engines are not at their ideal operating point when working at off-design conditions, such as when manoeuvring at slow speeds. What's more, slow sailing typically takes place during harbour approach, which is close to shore and consequently, human habitation. This in-harbour period has a higher direct impact on human health than the period spent sailing at sea, despite the duration being typically much shorter for an ocean sailing vessel (Banks et al., 2013). The exact proportion of times spent in each condition is of course highly dependent on individual vessels and their operation. Once berthed, in-harbour emissions do not cease, but ships typically provide their auxiliary load while in-harbour by running their auxiliary generators.

Electrification of shipboard systems provides extra flexibility, and offers the potential to help reduce fuel consumption and emissions. Electrified systems facilitate the integration of multiple sources of power and the use of energy storage, decoupling prime mover operation and power demand. This can ameliorate diesel engine operating points, since engine loadings can potentially be improved. Added flexibility is introduced by hybridisation of the powertrain, allowing power to be provided to the propulsion system via alternative means through the electrical system. Additional powering options are available when berthed in the form of onshore power supply.

In this paper, an assessment of the suitability and potential impact of the various electric solutions is performed, based on a real vessel and its operating profile including the in-harbour and harbour approach periods, using available data from the vessel's operation as the basis for quantifying emissions and fuel consumption levels. Firstly, hybridisation of the propulsion system is considered, with the fitting of a bidirectional auxiliary drive permitting electric propulsion at slow ship speeds. This is further expanded upon by the application of onboard batteries, permitting stored energy to be used to provide propulsion via the auxiliary drive. Finally, onshore power supply is considered, which enables the vessel to connect to the shoreside grid when berthed, such that the onboard generators can be turned off. This provides the onboard electrical load as well as charging of the batteries.

The benefits of auxiliary drives and shore supply have been studied previously as separate, single options. In Sciberras et al. (2015b), an auxiliary drive was considered, powered by the onboard generators during manoeuvring, where different machine choices and topologies were examined and discussed. Similarly, in Sciberras et al. (2015a) onshore power supply was studied for the berthed period, together with the impact on the shoreside electrical network.

In this paper, the complete operational profile for a case vessel is considered, and the performance of the auxiliary drive, shore supply and battery storage systems are assessed in terms of fuel consumption and emission savings. This is based on a real operating profile, sailed by a 138.5 m RoRo vessel between France and Spain along the Motorway of the Sea of Western Europe. The case vessel is a typical RoRo ship with a single shaft installation with a medium-speed engine driving a fixed speed Controllable Pitch Propeller (CPP) via a main reduction gearbox with the main particulars described in Table 1. The ship sails the regular return voyage of around 1850 km with a journey time of 60 h. The operation can be divided into three segments, namely at sea, manoeuvring and at berth. While at sea, the ship sails at a constant speed, before slowing down and sailing at a lower constant speed until berth is approached. These two conditions are illustrated in Figs. 1 and 2 respectively, based on actual onboard measurements. The proportion of time spent in each condition is summarised in Table 2, clearly

Table 1
Case vessel main particulars.

Deadweight	7629 t
Service speed	20.2 kn
Propulsion system	1 × CPP at 150 rpm
Main engine	1 × 14,480 kW at 500 rpm
Auxiliary generators	2 × 1421 kW