Electrical Power and Energy Systems 104 (2019) 840–852

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Review

Technical design aspects of harbour area grid for shore to ship power: State of the art and future solutions

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A R T I C L E I N F O

Keywords:
Battery energy storage system
Cold Ironing
Emissions
Harbour grid
Renewable energy resources
Vessels

A B S T R A C T

The cheap quality fuel used by diesel engines in marine vessels during a stay at berth is an environmental threat, and its widespread gaseous emissions are harmful to human health. Shore to ship power technology has been an essential requirement for reducing the emissions of maritime transport at harbour areas. Although this technology has already been implemented at certain seaports in several countries like the USA, Canada, Germany, Sweden, Finland, Norway, Netherlands, and Belgium, it is facing some technical and regulation problems. Shore to ship supply can be emission-free, economical and sustainable solution while utilising the renewable energy sources such as photovoltaic and wind energies along with battery energy storages. This paper aims to provide a comprehensive review of technical aspects, practices, existing standards and the key challenges in designing and modelling of a harbour grid for shore to ship power supply. This paper presents state-of-the-art and future marine solutions, discusses shore to ship power technology while considering voltage, frequency, power and other technical requirements of vessels at onboard and onshore. Moreover, this paper contributes in designing suitable models for the harbour area smart grids that can facilitate both onshore power supply as well as charging of batteries for the future hybrid and electric vessels.

1. Introduction

More than 90% of global trade is by seaborne vessels [1,2], and maritime transport plays a crucial role in the development of the world economy because it will be tripled in 2025 compared with 2008 [3,4]. However, it faces key challenges like dependency on fossil fuel, continuous increase in greenhouse gas (GHG) emissions, and some technical issues [1,5–7]. The current IMO report [1] predicted that increase in maritime CO_2 emissions by the end of 2050 would be 50–250% with respect to 2012 if some necessary actions for mitigating emissions and increasing energy efficiency would not be taken. One billion tons of carbon dioxide (CO_2) is from shipping, and the major sources of emissions to air from ships are main engines, auxiliary engines, and boilers [6]. There are various other types of emissions from the international shipping such as, carbon monoxide (CO), nitrogen oxides (NO_x), sulphur oxide (SO_x), volatile organic compound (VOC), ozone (O_3), and particulate matter (PM) [1,3,8–11], causing air pollution in harbour areas. Air pollution causes some dangerous health diseases including asthma, lung cancer, heart attack, chest infections and some other serious respiratory diseases [3,12–15]. These diseases are further responsible for about 60,000 deaths per annum along European, East Asian, and South Asian coastal areas [14]. Therefore, it is necessary to take the measures to avoid air pollution and preserve a healthy environment for the people, particularly in harbours. The concept of the green ship [2], green port [15,16], and zero emission port [17] will be the enabler for getting rid of emissions by employing renewable, sustainable and energy-efficient solutions at onboard as well as onshore.

In this regard, the IMO (International Maritime Organization) takes the actions for safe, secure and efficient international shipping by its regulatory framework and keeps an eye on shipping emissions, design, construction equipment, and operation. The IMO has set the international convention for the prevention of pollution from ships (MARPOL). It limits sulphur contents from ships in an Emission Control Areas (ECA) to 0.5% with effect from January 2015, and outside the ECA with effect from January 2020 or January 2025 depending on the outcome to be concluded by 2018. Currently, outside the ECA, the sulphur content limit is 3.5% by the MARPOL with effect from January 2012 [18]. European Commission is also striving to limit the emissions from maritime industry, set the rules, and implement the decisions in order to achieve the remarkable goals. The EU Directive 2005/33/EC [19], has recommended that the member states should use marine fuels with a sulphur content not more than 0.1% from January 2010 for the inland waterway vessels and the ships at berth in public ports. The EU Commission [5] has strongly recommended for cutting an overall EU

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https://doi.org/10.1016/j.ijepes.2018.07.051
Received 28 September 2017; Received in revised form 15 June 2018; Accepted 22 July 2018
0142-0615/

transport emissions by 60% including 40–50% from shipping by the end of 2050 compared with 2005. In order to comply with the IMO, EU Directives, and EU Commission, ships have to switch the marine fuel from the traditional sulphur-rich Heavy Fuel Oil (HFO) to low-sulphur Light Fuel Oil (LFO) such as: Liquefied Natural Gas (LNG) [20–28], Marine Gas Oil [26,28], distillates (diesel) [24,28], biofuels [23,25,29], and the mix of biodiesel with conventional marine fuels (blends) [29]. The other alternative ways to significantly reduce sulphur content from the HFO is to employ scrubber technology [22–26,28] onboard and it will be an attractive option especially for large vessels [24]. Moreover, the LNG prices are expected to lower in the next few years, and EU Commission [21], also supports the growth of LNG as an alternative fuel for replacing conventional polluting fuels. Besides this, onshore power generation by LNG can also reduce sulphur and particulate emissions on ports [30].

There are several environmental indices for measuring the ship emissions, but some ports use an Environmental Ship Index (ESI) practically and offer the incentives voluntary to the ships provided that the ESI is within a certain limit [31] for promoting the clean ships to reach sustainability goals. The ESI is developed by the World Port Climate Initiative (WPCI) and used by the ports as a tool to measure NO_x, SO_x, PM, and CO_2 emitted by the ships [32]. The California Air Resources Board is taking the measures for controlling toxic gases and emissions to air from auxiliary diesel engine operated by sea-going vessels, and it has set the regulations known as At-Berth Regulation. This regulation has directed to reduce and replace the onboard generation at berth by 80% from January 2020, either by shore-side electricity or with any other option of an equivalent emission reduction [33]. The EU 2006/339EC [34] demonstrates the shore-side electricity as a tool for improving air quality and human health nearby ports by reducing air pollutant emissions.

The ocean-going ships are considered as floating power plants because onboard power generation is high and it varies from few kilowatts to tens of megawatts [30] depending upon different types of the vessels. Conventionally, main diesel engines generate electric power for propulsion of vessels for manoeuvring and auxiliary diesel engines for ships services and their stay at the berth [4,6,35,36]. When vessels are at berth, typically they are using electricity for different purposes: lighting, ventilation, cooling, heating, communication, hoteling, loading and unloading [4,6]. The process of switching off all the diesel engines of the vessels while at berth and supplying the power to the vessels by shore-side electricity is usually termed as cold ironing. The term cold ironing is also well known in the literature by different names such as Shore-to-Ship Power, Shore-to-Ship Electrification, Shore-to-Ship Connection, Ship-to-Shore Connection, Shore Side Electricity (SSE), Shore-Side Power Supply, Shore Connection, Onshore Power Supply (OPS), Alternative Maritime Power (AMP), Alternative Marine Power System, and more recently High Voltage Shore Connection (HVSC) [2,4,6,8,12,18,37–40]. Initially, the U.S Navy used the term cold ironing when all ships had coal-fired ironclad steam engines. It was necessary to cool down these engines during a stay at ports, and ultimately these engines became completely cold [39]. Before the HVSC standard, many ship designers, ship owners, and port authorities were endeavouring to have a compatible system for the cold ironing in the world [41,42]. Currently, the HVSC standard [37] is a harmonized international standard set unanimously by the world leading organisations: IEC, ISO and IEEE for solving the technical issues of shore-side electricity.

The design of a harbour grid is a challenging task while taking into consideration environmental issues, technical issues including safety and protection issues, standard regulations, and continuous development in the field of marine technology. Harbour grids should be designed in such a way that it can solve multiple problems: reduction in emissions, dependency on fossil fuel, compliant with the power requirement of cold ironing and facilitating charging of batteries for future hybrid and electric vessels [41]. Renewable Energy Sources (RESs) at harbour area can reduce an overall carbon mass per kWh of electricity generated to a minimum value as compared to the mass of carbon exhausted by auxiliary engines at berth, i.e., 690–722 grams per kWh of electricity generated [9]. The objective of this comprehensive research work is to focus on state-of-the-art technology development in shipping and shore-ship power supply. This paper explains the existing practice, standards, barriers and technical challenges in implementing shore-ship power supply and future marine solutions. Moreover, this paper contributes to designing and analysis of the key features of some suitable models for the Harbour Area Smart Grid (HASG) that can supply power for ship's services during a stay at ports as well as charge batteries for future hybrid and electric vessels. The rest of the paper is organised as follows. Section 2 describes how cold ironing can be an emission-free and sustainable supply for the vessels berthed at the seaports in the harbour area. It highlights on adopted voltage levels and frequencies of the power supply of the ships at onboard and their associated voltage, power and cable requirements at onshore. The barriers and technical challenges in implementing onshore power supply for vessels are also discussed in this Section. In Section 3, present and future marine solutions for onboard and onshore are outlined. Section 4 focuses on designing the HASG and presents some modified models of the HASG, which are suitable for shore to ship power supply. The conclusion is presented in Section 5.

2. Onshore power supply: state of the art

This section addresses the fundamental questions: why an onshore power supply is necessary, how the onshore supply can be clean and sustainable, and why the onshore supply is necessary even if national grid electricity is more expensive and pollutant compared with electricity generated from auxiliary ship diesel generator. The several voltage levels and frequencies adopted by the vessels at onboard, standard onshore voltage and power requirements, cables and their connection requirements for shore to ship power supply for various types of the ships are also mentioned in this section. Since the voltage and power requirements of different kinds of the vessels are different, this section may help to familiarise with these requirements before designing a shipboard and onshore power system. Moreover, this section also outlines the main business barriers, key technical issues, and challenges of designing a harbour grid for shore to ship power supply.

2.1. Onshore power supply as an emission-free and sustainable supply

Onshore power supply is a suitable solution to make ports and harbours free from greenhouse gas (GHG) emissions, air pollutants (NOx, Sox, PM), vibrations, and noise pollution [6,8,11,18,34,37,38,40,42]. It has also been evaluated by the operational profile of a real case of RoRo vessel sailing between France and Spain that by applying the onshore power supply along with onboard Battery Energy Storage System (BESS) can significantly save fuel and emissions emitted by the ships [43]. Even with the onshore generation by the LNG can reduce CO_2 emissions by up to 40% [30]. Moreover, an application of the shore-side electricity can be emission-free, self-sustainable, reliable and efficient while utilising a maximum mix of RES into national grid supply [2,9,41,44]. Therefore, electric power generation from renewable sources by Distributed Generation (DG) such as solar, Wind Turbine (WT), geothermal, tidal, and wave energy resources at harbour area nearby the seaports [8,17,39,45,46] will be a suitable option to have an economic as well as a clean energy because they produce relatively low greenhouse gas [47]. The higher penetration of RES in the HASG can protect harbour area from the environmental pollution and bring many benefits to the terminal operator regarding saving the cost due to heavy demand charges billed by the utilities [45] and improving reliability and efficiency of power supply [47–49]. In future, a large energy storage [50,51], and plug-in hybrid power systems [52] might be a preferred option for ship services during