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Novel comparison study between the hybrid renewable energy systems on land and on ship

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ABSTRACT

The development of the marine industry led to an increasing amount of fuel consumption and greenhouse gases (GHG) emissions. However, it is hard to evaluate the payback and profitability of a hybrid renewable ship without preparing a complete investigation. A dearth of studies compares between the hybrid renewable energy systems (HRES) on land and on ships. Therefore, the main objective of this research work is to provide a novel comparison study for the differences between HRES on land and on ships, utilizing the well-known Hybrid Optimization of Multiple Electric Renewable (HOMER) software. To the best knowledge of the authors, this study is the first to do comparison regarding the HRES on land and on ships. This study is based on the project titled "Study on the Application of Photovoltaic Technology in the Oil Tanker Ship" in China. The load profile data used is real and accurate, depending on the ship navigation route from Dalian in China to Aden in Yemen. The hybrid photovoltaic (PV)/diesel/battery system is found to be the optimum system regardless if it is on land or on ships with annual capacity shortage of 0%, which means this system is a 100% reliable system. The optimal system on land consists of 10,000 kW of PV system, 2000 kW of diesel generators, 500 batteries and 2000 kW of power converters. The optimal system on ship consists of only 300 kW of PV system, 2000 kW of diesel generators, 10 batteries and 200 kW of power converters. The optimal system on ships is able to decrease the amount of GHG emissions by 9,735,632.5 kg during the project lifetime (25 years). In addition, it has capability to decrease the fuel-consumption amount by 2,010,475 L during the project lifetime. This represents an incentive factor to increase the installed capacity of the PV system on the ships that consequently decreases the fuel-consumption amount and the total fuel cost.

Contents

Abbreviations: AC, alternating current; ADVISOR, advanced vehicle simulator; B, battery; COE, cost of energy; DC, direct current; DG, diesel generator; DOE, Department of Energy; GHG, greenhouse gases; HEV, hybrid electric vehicles; HOMER, hybrid optimization of multiple electric renewable; HRES, hybrid renewable energy system; HVDC, high voltage direct current; L, liter; MARPOL, marine pollution; M, million; NASA, national aeronautics and space administration; NPC, net present cost; NREL, national renewable energy laboratory; PG/ESS, power generation/energy storage system; PV, photovoltaic.

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1. Introduction

In recent years, the pollution caused by the marine industry is considered twice what initially was assumed. The annual amount of CO_2 emissions from crude oil tankers and bulk shipping carriers is equal to the emissions from the whole USA [1]. Furthermore, the marine industry is one of the main responsibility for the greenhouse gases (GHG) emissions. Accordingly, penalties should be imposed against the pollution of the environment [2–4]. Indeed, the marine industry is considered as a conservative industry sector and has not implemented the new technology systems. This leads the international marine policy to encourage the ship-owners to install modern technology projects on their ships for achieving significant value of emission and cost reduction [5,6]. The shoreside electrical power supply to a ship at berth is an important issue regarding ship emissions and environment pollution. Utilizing renewable energy at ports will help reduce ship emissions and make them more environment friendly. The reduction in dock power supply significantly reduces dangerous port conditions due to power line maintenance problems [7]. According to the European Commission recommendations, the main European ports are preparing to install this technology, especially for port areas with high GHG emissions [8,9]. Moreover, decreasing the fuel-consumption of ships against unstable fuel prices and GHG emissions produced from international shipping are the challenge, which the industry faces currently [10,11]. The potential for fuel reduction is possible for new buildings besides existing ships by improving the technical and operational energy efficiency. Furthermore, ships owners and operators should rationalize their energy utilization and create energy professional solutions. The more the cost saving solutions are presented, the greater will be the GHG compliance [12,13].

To the best of the authors' knowledge, the hybrid renewable energy system (HRES) on ships has not been widely discussed, specifically the comparison between the HRES on land and on ships. However, there are several approaches, which have been employed regarding the HRES on land; some of the new approaches have been published in 2015 [14–18]. These approaches are mainly focused on how to get the optimal system from different HRES configurations that can reduce the amount of GHG emissions besides achieving least cost of energy (COE) and net present cost (NPC) [19,20]. On the other hand, it is not obvious if the hybrid renewable ships will be useful or not as ships change significantly in how they are operated and how their electrical power systems are designed. This means that it is hard to assess the benefits and profitability of a hybrid ships without performing a complete investigation [21,22].

The International Convention for the Prevention of Pollution from Ships (MARPOL) [23] enacted strict laws to limit the increase of GHG emissions from the conventional ships. The shipping industry has utilized the combination of a prime mover and an energy storage device for reduction of fuel consumption of conventional submarines [24–26]. The potential of a load levelling strategy through use of a hybrid battery/diesel/electric propulsion system was investigated in order to reduce exhaust gas emissions by reducing fuel consumption [27,28]. The work was based on operational data for a shipping fleet containing all types of bulk carriers [29,30]. The results for the global fleet indicated that savings depending on storage system, vessel condition and vessel type could be up to 320,000 t in NO_x, 70,000 t in SO_x and 4,100,000 t in CO_2 [31,32]. These represent a maximum 14% of reduction in dry bulk sector and 1.8% of world's fleet emissions [33,34].

HRES is composed of one renewable and one conventional energy source or more than one renewable with or without conventional energy source [35,36]. HRES works in stand-alone or in grid connected mode [37]. It is becoming a common topology for stand-alone electrification systems in remote areas due to the advancement in renewable energy technologies and electric converters. This can be used to convert the unregulated power generated from renewable sources into useful power for the electrical load [38,39].

Hybrid electrical systems with dc distribution are being recognized for commercial marine ships to meet the terms of new strict environmental policy, and to achieve higher fuel saving [40,41]. The advantages gained from electric propulsion systems have ever been since promoted the concept of all-electric ships, which provides a common electrical platform to supply the propulsion power and ships service loads [42–44]. On the other hand, the challenges of the conventional shipboard AC systems include the need for synchronization of the generation units, reactive power flow, inrush currents of transformers, harmonic currents, and three-phase imbalances [45–47].

A hybrid power train for ship crane operations has been investigated, using a lithium-ion battery in conjunction with auxiliary power generation as an alternative to a conventional power train using only diesel generator [48,49]. Crane operations in port has been simulated in order to quantify the potential economic gains of using hybrid power generation [50,51]. The study was based on a real open-hatch dry bulk vessel of 50,000 dwt, which is compared with a corresponding new building ships with hybrid auxiliary power generation [52]. The results indicated that the hybrid solution will lead to about 30% reduced fuel consumption and CO_2 emissions [53] while operating cranes, which amounts to annual savings of $110,000, with $450,000 savings over three years of operation, as well as reduced capital costs compared to the conventional power generation system [52,54].

The National Renewable Energy Laboratory (NREL) has developed ADVISOR [55] for the US Department of Energy (DOE). A tool can be used to evaluate and quantify the vehicle level impacts of advanced technologies applied to vehicles. ADVISOR is primarily used to quantify the fuel economy, performance, and emissions of vehicles that use alternative technologies, specifically Hybrid Electric Vehicles (HEV) architectures [56]. It employs a unique combined backward/forward-facing modeling approach. ADVISOR has been applied by researchers at NREL, industry, government, and academia to understand the impacts of various technologies on the performance, fuel economy, and emissions of a vehicle. In Ref. [57], an optimal algorithm is projected to reduce the fuel-consumption in different operating conditions. The energy storage