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Evaluation on the energy efficiency and emissions reduction of a short-route hybrid sightseeing ship

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ABSTRACT

This paper is to develop a coordinated control strategy of a ship with hybrid power and evaluate on the energy efficiency and emissions reduction of the case ship. The hybrid power system consists of 4-stoke diesel generator, solar panels and battery packs. A micro-grid power system was structured to offer an optimal combination of the three power sources in terms high efficiency and low emissions of the overall system. The control requirements for the developed micro-grid power system were analysed according to the principles of priority to use renewable energy. A power distribution control strategy was designed by applying the logic threshold method. A system simulation model was established and the simulation was carried out with MATLAB. An experimental test rig was built to evaluate the simulation results and develop the control system. The developed marine micro-grids power system has been applied on a case ship and run stably. Compared with the conventional power system, the performance of emission and economic of the hybrid system is studied with the case ships. The results of case ship and experimental have shown that the developed hybrid micro grid system can be managed effectively by the proposed control strategy. The emission of CO_2 is dramatically decreased in any cases and the energy cost is reduced considering for the ship life-cycle.

1. Introduction

Since ship emissions have become increasingly a serious problem, the technology of high energy efficiency and emissions reduction of shipping industry has brought a great attention from the international community. Air pollution from ships mainly comes from using heavy fuel oils for power generation. Although, these fuels are economical, they produce significant amounts of pollutant emissions (Rehmatulla et al., 2017). Designing and building new green ships with low energy consumption and low emission has become an important trend in the shipbuilding and shipping industry. On the one hand, several solutions exist for shipping to mitigate its emissions and transition towards low carbon shipping, and one of them is using renewable energy sources (Ammar and Seddiek, 2017). On the one hand, more and more are marine applications where traditional thermal engines are not the best option to cope with regulation limits and constraints, as in the case of passenger transportation in coastal cities waterways or in marine protected areas (Balsamoa et al., 2017). The electric propulsion technology is considered as the best candidate to take the place of the internal combustion engine propulsion. Therefore, in view of the higher requirements of environmental performance for traveling water area (IMO, 2016), the application of new energy technology and electric propulsion technology to develop a comfortable and environment-friendly sightseeing ship is an effective solution to solve the environmental pollution and improve the tourism quality.

With the development of electronics technology and control technology, the micro grid with new energy has been widely applied on land. The power output characteristics of new energy sources in the marine environment are not essential different from land-used type. However, the ship micro-grid system must deal with the special operating environment in marine application. In particular, the complicated and changeable working conditions during ship navigation would make the load power fluctuate and frequently change. When solar energy is concerned, it is also necessary to take into account of the influence on the power output by the limitation of the navigation area and the installation area of the solar panel. In addition, compared with onshore power system, one of the characteristics of ship power system is small capacity and large load. Therefore, the ship micro-grid, as a relatively independent system, has typical characteristics that distinguish it from the physical structures and characteristics of the power grid for land

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Nomenclature

G	Generator
PV	Photovoltaic
DC	Direct current
AC	Alternating current
PLC	Programmable logic controller
CAN	Controller area network
MPPT	Maximum power point tracking
SOC	State-of-charge
SFOC	Specific fuel oil consumption
P_{load}	Load power demand
P_{pv}	Output power of photovoltaic panels
P_{bat}	Output power of lithium batteries
P_{dg}	Output power of diesel generator

application. It is not possible to directly apply the micro-grid technology in the land grid to the marine application. Smith et al. (2016) mentioned in their research to combine different energy-efficient technologies in order to reduce shipping emissions. In this particular application, three energy sources are considered, including solar energy, lithium battery pack and diesel generators. The influence of the power quality (static and dynamic response of voltage and frequency) and the operation reliability of the micro grid system are to be studied.

At present, researchers and scholars around world have conducted research on the application of new energy sources in ships. Some research results have been obtained for using the solar energy and battery as an auxiliary power supply to ship application (Glykas et al., 2010). However, the study of solar energy and battery power as a component of ship's main power supply is still in the exploratory stage, especially in the research of ship's micro-grid technology. There has been very little literature published on relevant research. The DC Bus technology of ship power supply system, mixed with diesel generator and photovoltaic cells, is introduced by many previous researches (Bartelt et al., 2011; Jusoh et al., 2013; Zahedi and Norum, 2013a,b). It has the advantages of simplified transmission systems, high stability of system operation and transmission of active power. Also there is no frequency fluctuation and phase difference problem. The power supply system is reliable and can be easily achieved (Zahedi and Norum, 2013a,b). An energy management control system of the DC power system of the solar and lithium batteries has been developed by researchers already (Yu et al., 2013; Yu, 2013). Although the DC power system is easy to implement, there are also many drawbacks in ship application, such as small power capacity, low economic benefit, low reliability of equipment and so on. Reports (Wei et al., 2010; Sun, 2013; He et al., 2013) discussed the AC (alternating current) Bus technology of ship power supply for a system with a combination of diesel generator and photovoltaic cells. The report investigated the stability of power provision based on the maximum power output of solar photovoltaic and the synchronous generator speed regulation and excitation system control when the two power sources are operating in parallel. However, the system is lack of power storage and could not use solar energy to its maximum advantage.

Therefore, according to the characteristics and operation requirements of the sightseeing ship, aiming to the shortage of the existing ship's micro grid, this paper investigates a ship micro-grid power system which consists of photovoltaic cell, diesel generator and battery with AC Bus. At first, the topology of the ship micro grid power system is introduced, and the power control strategy and the optimization of the coordinated control are presented. Secondly, the paper presents the procedure of system modelling and simulation. The results of system operation stability and reliability were studied. Further, combined with electric propulsion technology, an energy management system is developed and applied on a sightseeing ship. Finally, A case study is carried out in order to estimate the energy saving and emissions reduction due to the installation of the hybrid power system.

The rest of this paper is organized as follows: Section 2 presents a topological structure of micro grid with AC Bus. In section 3, according to the output characteristics of different energy sources, the operation control requirements of the ship's micro grid are analysed, and the energy management control strategy is put forward. Section 4 introduces the related simulation research of the diesel generator, lithium-ion battery and photovoltaic, and develops a system simulation model of the micro grid. In section 5, the system under different load

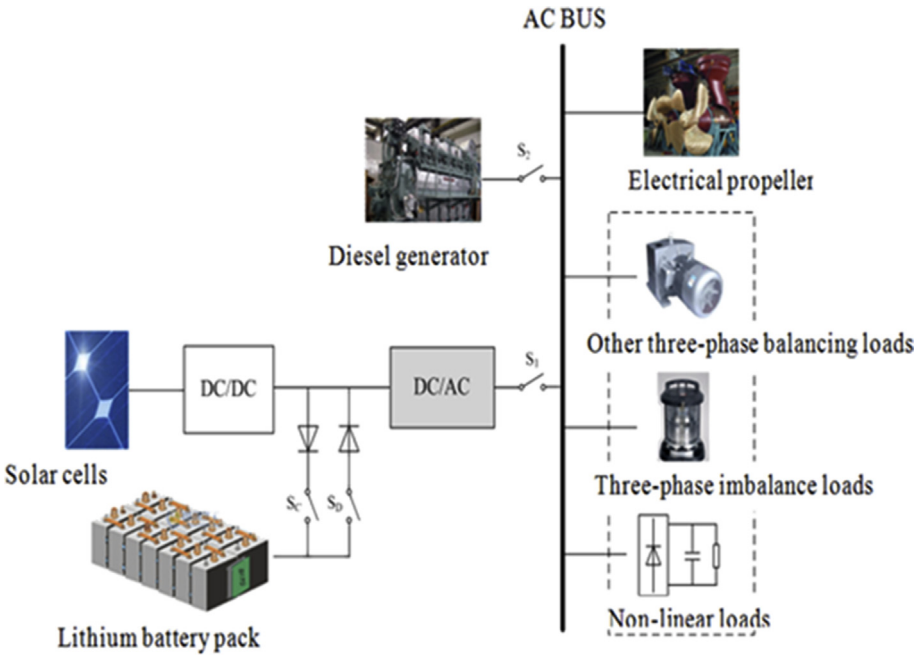

Fig. 1. The proposed architecture of ship micro grid system.