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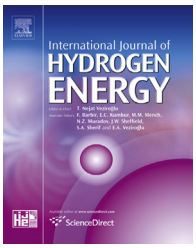

Integration of several renewable energies for internal combustion engine substitution in a commercial sailboat

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ABSTRACT

This paper presents the technical study of a commercial sailboat conversion, originally manufactured with an internal combustion engine (ICE), into electrical hybrid propulsion system with fuel cell and batteries. Batteries are charged with electrical energy from grid when boat remains at port. The used hydrogen is generated with the electrolysis of water using energy provided through the on-board renewable system (eolic, photovoltaic and marine generation). In order to check the viability of conversion mathematical modelling is used. Firstly, hull hydrodynamic resistance is obtained through Free!Ship software. Then, this result is implemented into a global model which is developed under Matlab/Simulink® environment. Furthermore, renewable energy and power systems are developed as Simulink® models and a logic controller manages them. In this study, the selection of all energy and power elements is shown. Real operation sailboat under real conditions is simulated. Finally, results obtained are compared with Spanish Navigation Normative to study a possible technical feasibility.

Introduction

The increase of energy consumption due to technological progress has been the cause of the depletion of fossil fuels [1]. Energetic and environmental problems have favoured the development of alternative energy conversion systems [2]. The role of power sources in the future energy economy and the progress of new renewable are the most widely used power sources, due to their high efficiency and relatively low cost [3], but the use of batteries in electric vehicles (EV) is low due to their limited range [4]. In order to solve this issue, and due to similarities between batteries and fuel cell systems, the Hybrid Fuel Cell Vehicles (HFCV) are one promising alternative [5]. Moreover, in last years the combined use of renewable sources as photovoltaic and eolic energy is extended in so-called Hybrid Renewable Energy Systems, (HRES) [6]. The use of HRES is more extended in the stand-alone applications although it begins to be implemented in transport applications [7].

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One problem of this kind of renewable energy is their seasonal nature. However, the use of hydrogen as a method of energy storage using electrolyzers could be implemented in order to solve this disadvantage [8,9]. So far, hybrid fuel cells are frequently used in land vehicles and to a lesser degree in stand-alone applications [10,11]. At the present time, the option of incorporating hybrid systems with fuel cell and batteries in boats or sailboats has not been extensively studied [12]. Moreover, the implementation of HRES in hybrid fuel cell systems is even less frequent. The main objective of this kind of boats is to reduce up to zero the emissions of traditional boats.

In a previous publication, authors presented a conceptual model and its corresponding modelization of a hybrid electric sailboat with renewable energy. Moreover, the correct operation was tested. Due to the lack of references about this type of simulation in marine vehicles, the authors present in this paper a real case of study in order to check the technical feasibility of renewable hybrid systems in sailboats [15].

In this paper, the electrifying of one commercial ICE sailboat into a hybrid system with batteries and fuel cell was developed. All this study was performed through data provided by manufacturer.

This electrification is completed with HRES in a conceptual sailboat. Individual models with each energy system have been developed and embedded in a global model.

The hull drag resistance and the motor power demand have been obtained from the plane of the hull. Renewable elements can have been implemented through characteristic curves and parameters provided by the manufacturers.

The strategies used in Energy Management Unit (EMU) applied to sailboats are not very extensive in literature. But as a starting point, the used EMU in fuel cell hybrid vehicles (FCHV) can be used [1]. A logic control strategic to manage all these system has been developed.

ICE sailboat conversion

Zero emissions boats or sailboats are not one of then main objectives of studying in transport applications with renewable energy. Fuel cell hybrid systems have been implemented in some types of ships (catamarans, boats and sailboats) [13,14].

In a previous publication, authors have developed a conceptual sailboat design and its modelization. In this paper, such work is applied in order to considerer the technical viability of the ICE commercial sailboat conversion into a battery/fuel cell hybrid power system [15]. The conceptual yacht scheme is shown in Fig. 1. In which a commercial sailboat, the Hanse 355 with 10.50 m of hull length, originally with one ICE of 13.3 kW is electrified with a hybrid system. Table 1 shows technical specifications of Hanse 355 Yatch. Propulsion would be carried out with an electric motor of 10 kW; the motor electric supply is provided by a fuel cell (PEMFC) and a system of batteries in the hereinafter referred as Fuel Cell Hybrid Boat (FCHB). The electric energy supply of FCHB is possible in two ways. The first way in which electric energy is provided to the FCHB is through electric grid, and it is stored in the battery system. Furthermore, sailboat counts with a HRES with several renewable sources of energy: eolic generation, photovoltaic panels production and marine generation. HRES energy is stored into hydrogen form using an electrolyzer.

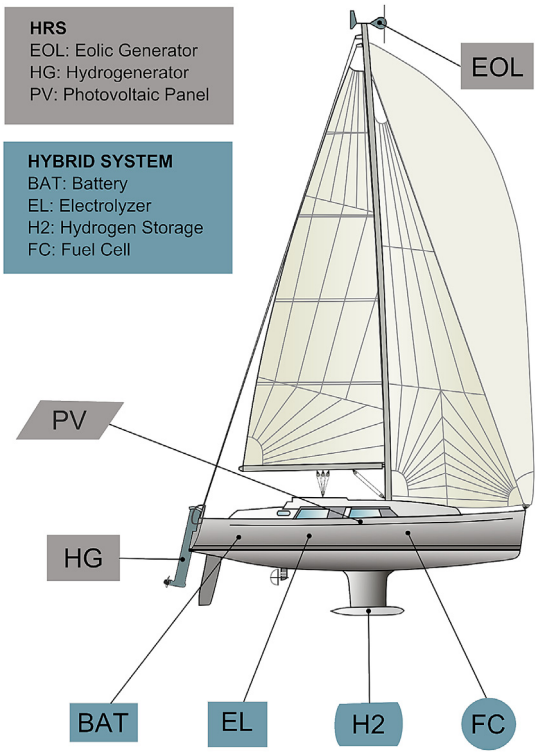

Fig. 1 – Conceptual design of zero emission sailboat.

Table 1 – Hanse 355 technical specifications.

Length over all	10.56 m
Load waterline length	9.60 m
Design beam	3.55 m
Hull draft	0.46 m
Maximum draft	1.85 m
Ballast	1750 kg
Diesel engine	13.3 kW/18 hp

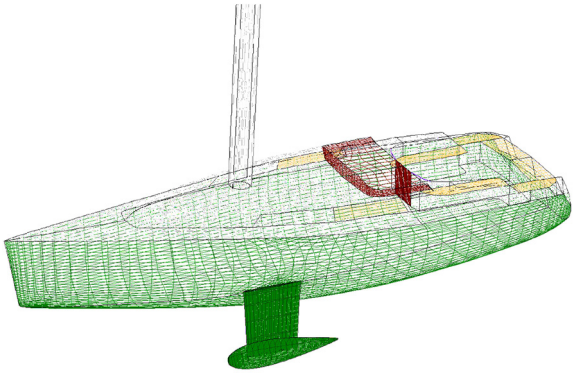

Fig. 2 – Hanse 355 modelled under Free!Ship® software.