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Modelization of hybrid systems with hydrogen and renewable energy oriented to electric propulsion in sailboats

Víctor Alfonsín [a,*], Andres Suarez [a], Angeles Cancela [b], Angel Sanchez [b], Rocio Maceiras [b]

[a] Defense University Center, Escuela Naval Militar, Plaza de España 2, 36920 Marín, Spain
[b] Chemical Engineering Department, EEI, University of Vigo, 36310 Vigo, Spain

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ABSTRACT

This paper presents a conceptual model of a hybrid electric sailboat in which energy from electric grid is stored in batteries and energy from renewable energies (eolic, solar and hydro) is stored as hydrogen. The main objective of this model is to study the viability of electrifying traditional sailboats with internal combustion engines into hybrid systems with batteries and fuel cell. The most important advantage of this design is the possibility to reduce up to zero emissions of traditional sailboat. Conversion of renewable energy to hydrogen is performed through an electrolyzer and post conversion to energy is carried out by a fuel cell. The fuel cell with the batteries forms the hybrid system (batteries-fuel cell) for propulsion electrical energy supply. In order to model the boat dynamic and energy systems, modular mathematical models were developed under Matlab®-Simulink®, using a fixed-step solver for the simulation of global model. A simulated logic controller manages the global model. In this paper, many models have been used: some of them are based in literature models and others were developed from experimental data. A control strategy has also been developed to manage energy flows and then it has been embedded to Matlab® language. The global model permits test the performance of the sailboat.

Introduction

The increase of energetic and environmental problems has favored the development of alternative energy conversion systems [1]. Transport machines with only internal combustion engine (ICE) are being replaced by hybrid systems using two or more power sources [2,3]. Battery systems are the most widely used power sources due to their high efficiency and relatively low cost [4]. On the other hand, fuel cell systems are a new emerging technology that could solve environmental problems, contribute the accomplishment of Kyoto Protocol and besides it can help to solve the oil dependence [5–7]. Due to similarities between batteries and fuel cell systems, their combined effect promise great results [8].

Furthermore, in recent years the implementation of renewable sources as photovoltaic and eolic energy in Hybrid Renewable Energy Systems (HRES) is becoming popular for power generation [9]. The main disadvantage of these type of renewable energy sources is their seasonal nature, which

* *Corresponding author*. Tel.: +34 986 804942.
E-mail addresses: valfonsin@cud.uvigo.es, valfonsin@gmail.com (V. Alfonsín).
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means great variability over time [10,11]. Generation of hydrogen based on renewable resources using electrolyzers could become the nexus for the implementation of this technology in hybrid systems [12,13].

Plus land vehicles [14,15], it is possible to incorporate fuel cell and battery hybrid systems in boats [16]. Hydrogen production is performed with renewable energy provided by several photovoltaic panels and small eolic generators located in the own boat. Furthermore, if a sailboat is selected, this energy production can be increased during the sail navigation with one or more hydrogenerators.

For this type of systems, where many power sources are mixed, mathematical simulation has become in object of study for battery electric vehicles and all kind of hybrid configurations and even specific software has been developed [17–19]. However, there is a lack of information about battery electric ship simulations and even less about energy renewable sources applied in these kinds of vehicles.

There is not any information about Energy Management Unit (EMU) strategies in the case of HRES implemented in sailboats. But, it is possible to find a vast amount of information in many application areas as transportation, distributed generation or portable applications. Some of most important are: direct integration, single converter based or multiple converter based [20].

In this paper, a conceptual zero emissions electric sailboat is studied. Renewable energy sources (photovoltaic, eolic and hydrogeneration), energy storage with batteries (in the case of electrical energy provided by the grid) and an electrolyzer-fuel cell system (for renewable energy) are implemented. Subsequently independent modular models with each energy system has been developed in Matlab®/Simulink® and embedded. All of these individual models are managed by a logic controller implemented in Matlab®.

Conceptual design

The idea of zero emissions ships is not new, several kinds of ships exist with some of the zero-emission characteristics and even some of them have become commercial. Configurations with batteries, fuel cells or both (hybrid systems) have been developed and applied to catamarans, yachts and boats [21–24]. A conceptual sailboat design with a hybrid battery/fuel cell energy system has been raised. Battery system is responsible for storing electrical energy from the grid, and whole of fuel cell, electrolyzer and hydrogen canisters are responsible for storing renewable energy.

Renewable generation is provided through three sources: wind turbines, photovoltaic panels and hydrogeneration

1. Wind turbines placed to the top of the mast (only one) or placed in the stern (one or two elements are possible), and whose operation relies on wind power and it is operative during the sailboat cruise or even when sailboat remains in port.
2. Photovoltaic panels, placed on ship hull, whose operation it is possible during the ship cruise or when ship remains in port, depending on the effective radiation.
3. Renewable energy source is hydrogeneration. One or two marine generators are responsible for electric energy generation during sail navigation, without electric motor operation.

Renewable energy flows to the electrolyzer where is converted to hydrogen, and then it is stored in tanks or canisters. Optimal hydrogen storage devices are metal hydride canisters which due to their elevated weight are perfect to be used as boat ballast. When control decides to supply energy to system, fuel cell device converts hydrogen to electrical energy. All implemented devices are part of a conceptual idea for zero emission sailboats, and one possible distribution is depicted in Fig. 1.

Model description

Once a conceptual design for a zero emission sailboat has been established, it is necessary to size the magnitude of each element and even define the number of them that may be needed. A design and analysis powerful tool for this procedure is mathematical simulation with Matlab®-Simulink® software.

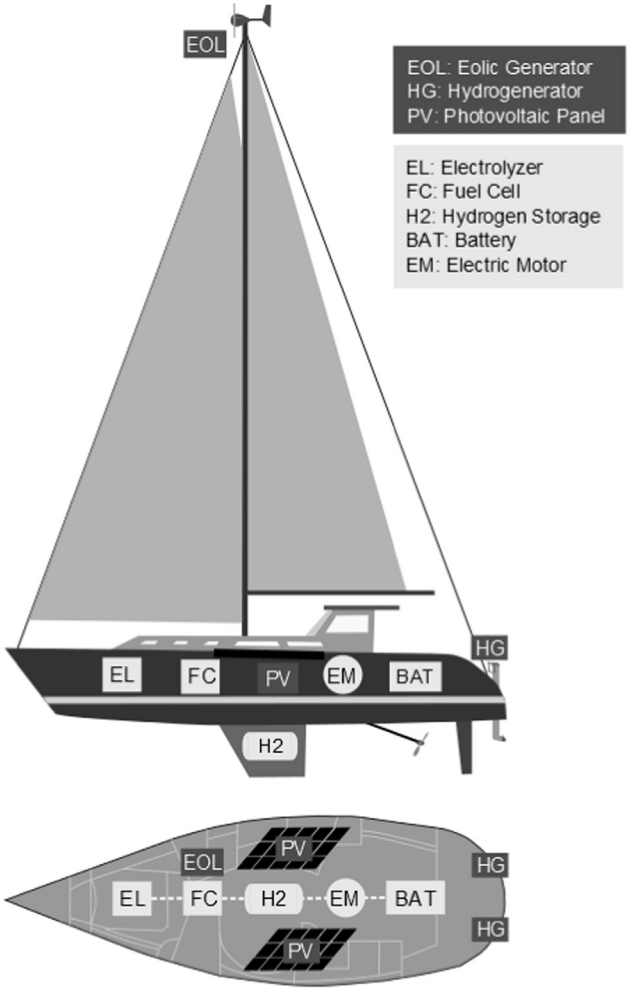

Fig. 1 – Conceptual design of a zero emission sailboat.