Modelization of a Hybrid System With Renewable Energy for Electric Propulsion in Boats. Application to a Robotic Floating Platform

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Abstract *– A model of a hybrid system with renewable energy for electric propulsion in boats in which energy generated by photovoltaic modules and hydrogenerator is stored in the main battery which exerts its function as central element of a renewable cycle is presented. Additionally, hydrogen plays a role being generated by an electrolyzer for later to be stored in cylinders aboard in order to generate electric power by a fuel cell. Both, batteries and cylinders can be used to feed the different elements of the system, more specially the thruster while the excess of power is stored in another battery which is auxiliary and it is able to feed the first when it is necessary.*

Keywords *– Photovoltaic, Hydrogen, Fuel Cell, Floating Platform, Renewable Energy*

I. INTRODUCTION

At the dawn of the twenty-first century, we have available a variety of options to meet our energy needs. However, we obtain our most of energy through combustion.

Our fuels are predominantly hydrocarbons, chemical compounds containing hydrogen and carbon. Hydrocarbons are high-energy fuels, but its combustion introduces a variety of pollutants in the atmosphere.

This not only results in smog and respiratory diseases, but also produces large amounts of carbon dioxide. This gas traps heat from the sun in the lower layer of our atmosphere, raising global temperatures. Even without considering the pollution, we must face the fact that most of our fuels are not renewable. The amount of these fuels to be drawn from the earth is limited. When it runs out, we must find new sources of energy [1].

The increase of energetic and environmental problems has favored the development of alternative energy internal combustion engine are being replaced by hybrids systems using two or more power sources. Battery systems are the most widely used power sources due to their high efficiency and relatively low cost. On the other hand, fuel cells 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. Generation of hydrogen (also based if possible on renewable resources) using electrolyzers could become the nexus for the implementation of this technology in hybrid systems [2].

It is well known that ROVs are excitingly useful to study the ocean where a number of deep sea animals and plants have been discovered or studied in their natural environment. Furthermore, they are capable of multiple purposes as military for tasks such as mine clearing and inspection, salvage, etc.

Installation of marine renewable energy structures, such as offshore wind turbines and marine hydrokinetic devices, will require a variety of visualization and monitoring equipment to properly survey the sea floor for initial installation, cable lay, and post-installation, monitoring and maintenance tasks that can be carried out by ROVs [3].

II. MODELIZATION OF A HYBRID SYSTEM ON BOATS

The following paper shows the feasibility of a conceptual model with an electric hybrid system (fuel cell - battery) in which energy is obtained from renewable sources. The centerpiece of the system is a battery that is charged by renewable energy generated aboard thanks to the solar modules, hydrogenerator or hydrogen stored in bottles which generates electricity through a fuel cell also aboard. When power demand is not possible to get through renewable energy, batteries provide the necessary power.

Thus, depending on the power requirements, the battery as well as the fuel cell and cylinders could be designed depending on average irradiance got by the solar modules.

III. APPLICATION TO A ROBOTIC FLOATING PLATFORM

As consequence of the model, all the points described before can be extrapoled to any boat successfully. The concept of a robotic floating platform can be chosen as demonstrative model.

The floating platform is remotely controlled from port or from another boat. It would have all the elements before listed but the electrolyzer which is placed onshore due to characteristics of the platform that do it non-viable aboard (relatively small dimensions, weight, power demand, etc.). In this manner, it navigates using renewable energy exclusively.

The complete model would consist then of the following elements: solar photovoltaic module, hydrogenerator, electrolyzer, hydrogen storage bottle, fuel cell, battery and the propeller [Fig.1].

It has been designed in order to support another boats or marine devices for naval inspections -for example, ROVs- while the platform is stopped. It is because the power demanded for propulsion is zero whereas the power generation can be maximized until 3 kW by only photovoltaic energy or even more if it is necessary.

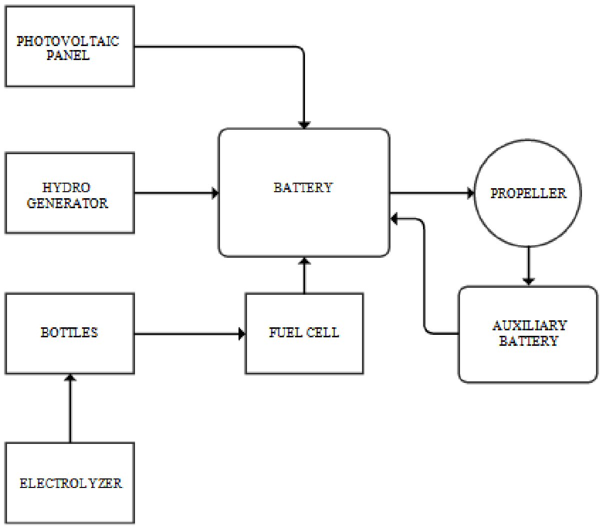

Fig. 1. Flux diagram of renewable energy cycle

The present chapter pretends to develop the listed elements but the propeller which should be chosen by the particular power network and the analysis of the rest of the elements.

1. Photovoltaic Panel

An essential reason why the solar floating platform is designed is to place on it a photovoltaic module which is capable of supplying energy requirements.

It is necessary to determine the monthly average irradiance in order to estimate the square meters of solar cells required for a certain power.

This model has been modified [4] to estimate the maximum power output in operating conditions [5]

$$P_{mp} = \frac{G}{G_{ref}} P_{mp,ref} \left[1 + \gamma\left(T - T_{ref}\right)\right] \quad (1)$$

Where G is the incident irradiance, G_{ref} y T_{ref} are the irradiance and temperature refer to standard rated conditions (SRC), respectively, the power correction factor for nominal temperature is γ and T is temperature.

Any photovoltaic module will be typically rated at 25°C under 1 kW/m^2. However, in reality, they typically operate at higher temperatures and at somewhat lower insolation conditions. In order to determine the power output of the solar cell, it is important to estimate the expected operating temperature of the photovoltaic module. The Nominal Operating Cell Temperature (*NOCT*) is defined as the temperature reached by open circuited cells in a module under the conditions as listed below [6]:

Table 1

Irradiance = 800 W/m^2	Air Temperature = 20°C
Wind Velocity = 1 m/s	Mounting = open back side

Given that data can be used the following equation to calculate the operating temperature of the cell [6]

$$T_{cell} = T_{air} + \frac{NOCT - 20}{80} \cdot S \quad (2)$$

Where T_{air} is air temperature and S is irradiance in mW/cm^2.

The particular study for a standard photovoltaic multy-cristalyne module of 255 Wp (maximum power) [7] is showed in the next graphic where irradiance (W/m^2) and power (W) values obtained were approximated to a polynomial function:

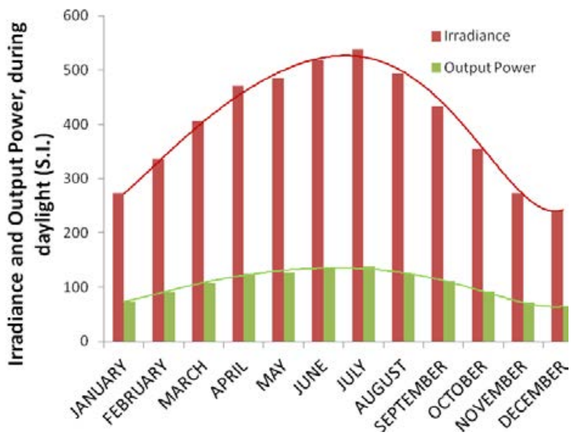

Fig. 2. Irradiance and Output Power throughout a year

In [Fig.2] output power is able to be obtained knowing irradiance values for the place of Cartagena. Irradiance used is the monthly average amount of the total solar radiation incident on a horizontal surface at the surface of the earth for 3-hour intervals of GMT during the given month, averaged for that month over the 22-year period

(Jul 1983 - Jun 2005). These data were obtained from the NASA Langley Research Center Atmospheric Science Data Center [8] and weather base [9].

Nevertheless, irradiance is usually given for a whole day; however, photovoltaic module won't generate output power at night, but just in daytime. Therefore, only the hours of sun interval was taken to obtain irradiance values.

[Fig.3] and [Fig.4] are the curves for irradiance as well as output power got by the system in opposite seasons corresponding to year 2000.

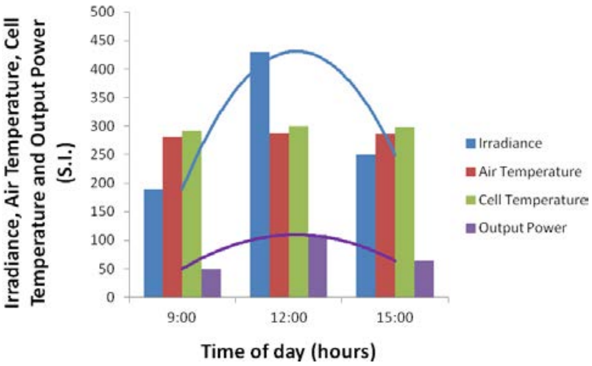

Fig. 3. Curves in a arbitrary winter day

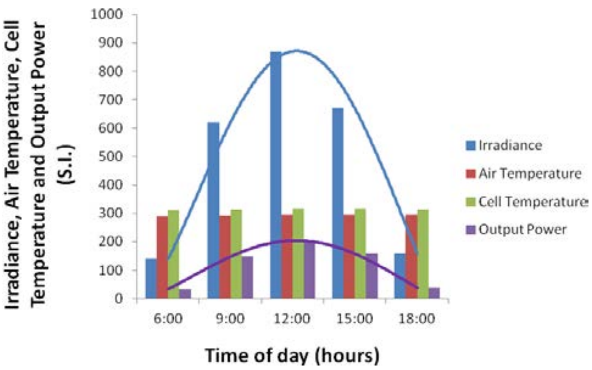

Fig. 4. Curves in a arbitrary spring-summer day

Over the same 22-year period, it is possible to obtain the relation between irradiance and power. The resulting graphic is approximately a straight line [Fig.5].

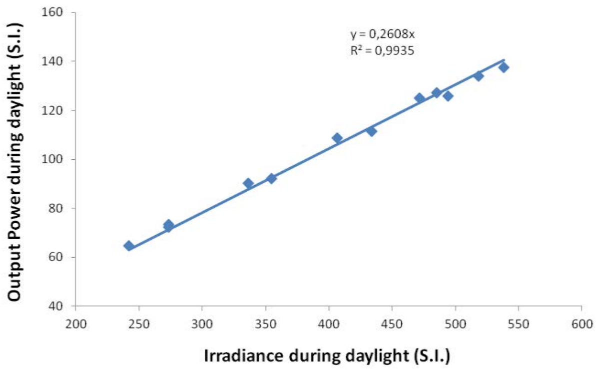

Fig. 5. Output Power vs. Irradiance for a year

Using again the year 2000 of reference, it is also useful to get the curves for an entire month as it is represented in [Fig.6] and [Fig.7].

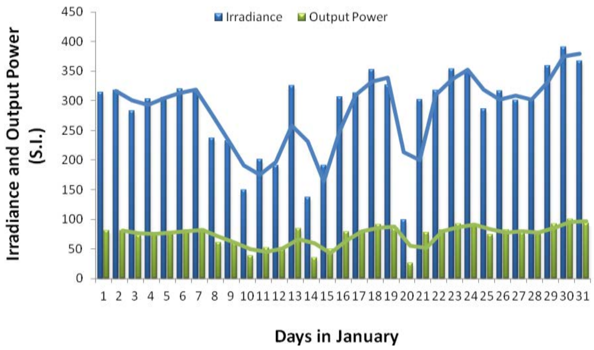

Fig. 6. Particular study for an arbitrary winter month

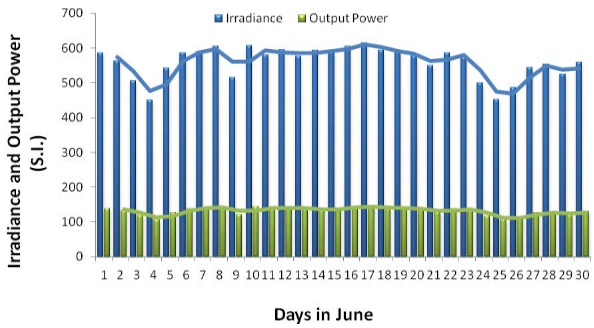

Fig. 7. Particular study for an arbitrary spring-summer month

Moreover, daily 20-years average irradiance has a value of 102.39 W.

Then by setting a certain basis capacity, the necessary photovoltaic area can be obtained. In the particular model, it results in 57.49 m^2 to reach 3000 W (and taking in consideration a +20% power margin); it is enough, *e.g.*, to feed a ROV of relatively small-medium dimensions as it was proposed.

Finally, it is possible to get a fast preliminary concept about the dimensions of the platform, which could be 14 × 5 m (length × beam).

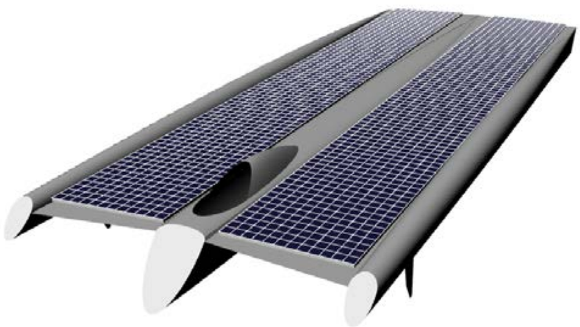

Fig. 8. Device design

2. Hydrogenerator

The hydrogenetor is simply a lightweight device that uses the platform speed through the water to drive a turbine and get electric power.

Characteristic curves are presented in the next graphic.

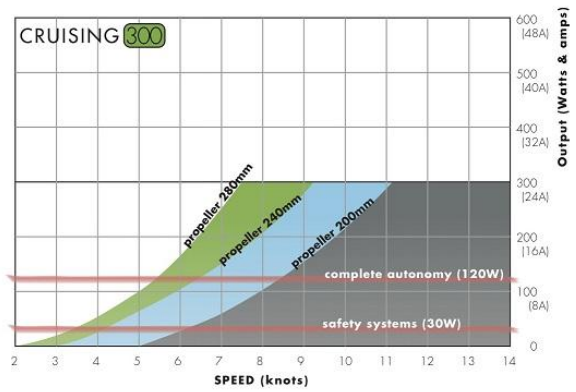

Fig. 9. Power - Speed curves of different hydrogenerator models [10]

For calculations, the three-blade propeller of diameter 280 mm was chosen. The battery curves that are represented later take 7.5 knots as navigation speed. Therefore 300 W would be generated by a hydrogenerator.

3. Battery

The battery is a crucial element of the system. There will be a main battery that will always be operating as central element of the system and the renewable energy cycle. It should to stay full charged in ideal conditions the greater part of the time while auxiliary battery is charging or discharging depending of power flow. The usefulness of it is revealed when renewable energy is insufficient to feed the propeller or another element for a specified time interval.

As with the photovoltaic model, the auxiliary battery performance can be obtained from a curve as function of power flow in the time.

With the technical data of the batteries, curves were plotted for sailing conditions in two favorable and unfavorable days as before.

As consequence, results indicated defects (battery discharging) and excess of power (battery charging) in January and June, respectively, as expected.

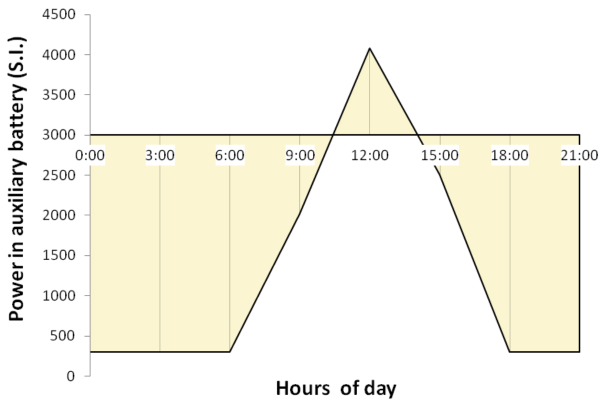

Fig. 10. Power in the auxiliary battery in an arbitrary winter day

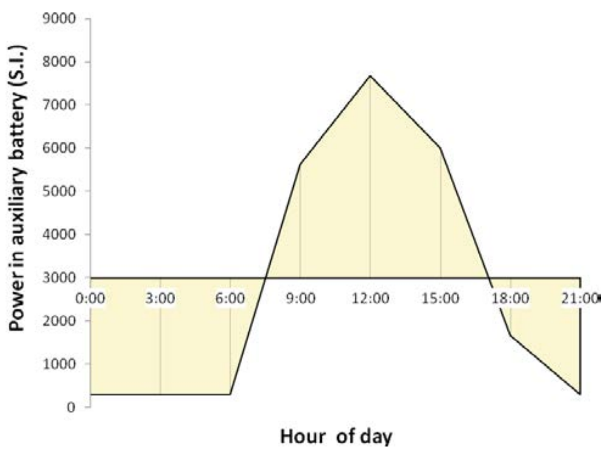

Fig. 11. Power in the auxiliary battery in an arbitrary spring-summer day

4. Electrolyzer

An electrolyzer is simply a device that ultimately allows the generation of hydrogen from an input power supply.

In the application filed, the electrolyzer will be generating hydrogen and compressing it in bottles, this could be done directly from the output pressure of the electrolyzer or through the intermediate step of a compressor.

The idea suggested here is to have a hydrogen production plant onshore, which is responsible for quickly fill the empty bottles which boats that integrating hybrid energy storage model here exposed will bring.

5. Fuel Cell

In a fuel cell, hydrogen can be used to produce electricity. It uses a chemical reaction to provide an external voltage as does a battery, but differs from this in that fuel is continuously supplied in the form of hydrogen and oxygen gases. It can produce electricity with higher efficiency than burning hydrogen, because it is not subject to the second law of thermodynamics. Furthermore, its only product is water, so it is free from pollution.

It is important to establish the fundamental differences between conventional batteries and fuel cells. Conventional batteries are energy storage devices, that is, the fuel is inside and produce energy until it is consumed. However, in the fuel cell reagents are supplied as a continuous flow from the outside, allowing uninterrupted power generation as long as there is hydrogen in the bottles.

Energy efficiency of a fuel cell is generally between 40-60% in these cases.

As mentioned, the hydrogen consumption of the battery is a function of the power we can get from it. In addition, the total efficiency is relatively stable at approximately 43% (value enclosed between 20% and 100% of rated load based on LHV of Hydrogen, according to manufacturer). The lower heating value (also known as net calorific value) of a fuel is defined as the amount of heat released by combusting a specified quantity (initially at 25°C) and returning the temperature of the combustion products to 150°C, which assumes the latent heat of vaporization of water in the reaction products is not recovered. Knowing this, we can calculate the output power depending of hydrogen flow generated by the electrolyzer.

Hydrogen LHV are 120 kJ/g and 1 L of hydrogen is 10.8 kJ about in terms of energy equivalent. Keeping these values as constant, energy obtained from 1 liter of hydrogen can be calculated

$$E_{out} = \eta \cdot 10,8 \qquad (3)$$

Where η is the fuel cell efficiency and E_{out} is got in kJ.

[Eq.3] provides that 1 LPS or 60 LPM of hydrogen generates 4.64 kW. Establishing a power reserve, the necessary hydrogen flow to feed the fuel cell is easily calculated.

6. Bottles

Metal hydrides are very attractive for hydrogen storage because they are safe and have good storage characteristics. Currently many of the commercially available metal hydrides are rare earth metal hydrides with hydrogen storage capacities environment to 1.4% by weight, which makes these materials more efficient storage volume of hydrogen as a compressed gas or as liquid hydrogen.

For controlling hydrogen flow and the power generated, an adjustable nozzle section can be installed to decrease or increase the pressure and thus the flow of hydrogen leaving the storage system to the battery depending on the power demand.

However, the storage system must have a finite and limited size by the space occupied by it.

Bottles capacity is given by manufacturer as well as the internal and discharge pressure and temperature. This capacity is often given in Normal Litres (NL), *i.e.*, 1 atm and 275.15 K. It is interesting to know, what the referred volume in load and discharge conditions is. We can do this by means the ideal gas law. This way, it could obtain the necessary volume for a determinate power.

Knowing the volume and the power obtained from fuel cell model, capacity of the hydrogen storage system can be estimated as well as the discharge time

$$t = \frac{V_{dc}}{Q} \qquad (4)$$

Where V_{dc} is the volume occupied by hydrogen in discharge conditions and Q the necessary hydrogen flow in the fuel cell (assuming Q constant).

Our calculations show an amount of 221.7 moles of hydrogen, *i.e.*, 366.29 L in charging conditions (15 bar, 25ºC) or 2747.92 L in discharging conditions (2 bar, 25ºC). To achieve, for a determinate condition, a power supply of 1500 W with this system, a discharge of 19.4 LPM of hydrogen would be required.

Finally, by applying [Eq.4], the discharge time of a bottle is 141.64 minutes or 2.36 hours.

CONCLUSIONS

In this paper a model of hybrid system with renewable energy for electric propulsion in boats applied to a robotic floating platform in order to lead the crossing towards an emission-free model to the atmosphere is presented. Weather characteristics studied were more favourable and stable in summer than winter. By setting a power basis, we could approximate the battery working curves and seeing time intervals where the system could operate without more help that the photovoltaic module as well as intervals in which another renewable energy sources have to give support. Considering daily 20-years average irradiance it has been reported a value of 102.39 W for a standard photovoltaic module. By applying a +20% power margin, it resulted in 57.49 m^2 to obtain 3000 W. Examples of hydrogen bottles in this model are rated at 5000 NL and charge pressure 15 bars. A single bottle could generate 1500 W during 2.36 hours. However higher pressure bottles can be used resulting in greater amounts of power. Though high pressure storage can be dangerous, remote control system here proposed is advantageous for adapting the model to other marine systems in order to reduce pollution.

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