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Sizing of a solar/hydrogen system for high altitude long endurance aircrafts

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ABSTRACT

High altitude long endurance (HALE) aircrafts are aerial platforms operating in the stratosphere, providing relay services for wireless communication networks. These platforms are an alternative to increase the effectiveness of future communication. Nevertheless, the power system is a key part that determines the implementation and feasibility of these platforms. One effective and renewable option to power an HALE aircraft is a photovoltaic system (PVS) with hydrogen storage. In this paper, the simulation of the solar/hydrogen closed loop system is carried out for a parametric combination of the subsystems power. Power consumption of the propeller was determined as a function of the aircraft weight in steady flight and in still air. In order to obtain the optimal nominal powers the efficacies are calculated at hourly intervals over the course of the year by means of an analytical energy balance. The proposed method was implemented in an algorithm, which allows fast estimation of the actual time of flight and the system efficiency. Finally, the energy system of three HALE aircrafts was analyzed in relation of their wing area and total and empty mass.

Introduction

At present, the fast progress of technology is without doubt one of the key progress indicators for every country. Furthermore, communications play an important role due to the direct impact on the economic and social development. Technology and communication provide unlimited opportunities in social as they play a vital role in human existence. Moreover, energy also plays an important role; in a globalized world a lack of energy makes impossible the proper functioning of the production system to deliver the goods and services that people and societies need. In this way, it is clear that the current communication systems are closely bound up to energy. In recent years, the terrestrial optical fiber communications system has grown enormously. In the same way, satellite communication systems have shown a remarkable development. The latter dominated basically by three reasons: 1) there are places that terrestrial systems cannot cover, 2) the need of satellite communications in natural disasters, wars, etc. and 3) the demand cannot be covered only with the use of optical fiber [1]. Satellites are also attractive for interconnection of geographically distributed high speed networks [2].

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Nomenclature

A_{PVS}	Area of photovoltaic system
A_S	Area of aircraft wing
C_D	Drag coefficient
C_L	Lift coefficient
D_f	Drag force
E_{ffS}	System's global efficacy
G_i	Extraterrestrial radiation
G_{SC}	Solar constant
L_f	Lift force
N	Day of the year
P_{TL}	Power for level flight
$T_{f,actual}$	Actual time of flight
$T_{f,max}$	Maximum time of flight
V	Relative airspeed
W	Weight
δ	The solar declination, degrees
$\varepsilon_{deficit}$	Energy deficit
ε_{in}	Electrical energy output of photovoltaic system
ε_{NHc}	Electrical energy of hydrogen consumed by fuel cell
ε_{NHg}	Electrical energy of hydrogen generated by electrolyzer
ε_{out}	Electrical energy consumed by the electrical load
ε_s	Electrical energy stored in the hydrogen storage system
$\varepsilon_{surplus}$	Energy surplus
η_{FC}	Fuel cell efficiency
η_{PE}	Electrolyzer efficiency
η_{PP}	Propeller efficiency
η_{PVS}	Photovoltaic system efficiency
η_S	System efficiency
ρ	Air density
ω_{PVS}	Mass density of photovoltaic system
ω_{URFC}	Energy density of unitized regenerative fuel cell
ω_{MHSS}	Hydrogen storage capacity

Abbreviations

BOP	Balance of plant
FC	Fuel cell
GEO	Geosynchronous equatorial orbit
H_2	Hydrogen
HALE	High altitude long endurance
LEO	Low earth orbit
MHSS	Materials-based hydrogen storage system
PE	Electrolyzer
PMHSS	Nominal power of the materials-based hydrogen storage system
PPVS	Nominal power of the photovoltaic system
PURFC	Nominal power of the unitized regenerative fuel cell
PVS	Photovoltaic system
URFC	Unitized regenerative fuel cell
UAV	Unmanned aerial vehicle

The traditional satellite communication system employed a geostationary satellite, located in geosynchronous equatorial orbit (GEO). However, the quite far distance, between the geostationary satellite and the earth give in a signal delay problem. In recent years, considerable attention has been paid to low-earth-orbit (LEO) satellite communication systems [3]. LEO satellite systems provide low propagation delay which enables real-time communications as well as higher throughput compared to geostationary links [4]. However, there are still various challenges in communication satellites. The three most important are: 1) the launch is complicated, 2) the cost of production, start-up, operation and maintenance is high and 3) the recovery is not economically viable, which implies severe aerospace pollution problems. For this reason, in recent years alternative communication systems have been developed.

High altitude long endurance (HALE) aircrafts are considered by many researchers a viable option because of they can travel in intermediate altitudes, low speed and cover specific areas, providing information with high capacity and spectral efficiency [5].

In addition, there are a variety of specific applications regarding communications, monitoring large areas of interest, scientific applications, or other mission requiring high resolution images or data almost immediately. These types of aircraft could function as a geostationary satellite with the advantage of lower cost and more flexible operation [6]. However, it should be recognized that a major inconvenient for HALE is the energy required for the operation of the aircraft during long periods of time. Many research groups around the world have paid great attention to the development of the solar-powered HALE aircrafts [7]. The use of renewable energy in these applications improves significantly the profitability and environmental efficiency of HALE [8]. However, due to its intermittency solar energy is not the ideal energy source, requiring a safe and reliable power storage system.

Storage is a crucial factor for the development of these aircraft due to the fact that batteries usage is limited by the reduced specific power density. Also, their lifetime is drastically affected with deep discharge cycles; efficiency is at least 80% [9] and requires frequent maintenance such as water addition and gas release [10]. Other disadvantages of batteries are too heavy for mobile use; in many cases occupy about 50% of the total mass of the aircraft [11]. A power system for HALE aircraft needs more energy than provides by batteries. The use of hydrogen (H_2) as an energy power source is considered a viable option for many researchers [12], especially for mobile applications. Hydrogen is a suitable energy storage medium that is free of carbon and other impurities; it is also the most abundant element in the universe [13]. A system of production and energy storage based on hydrogen technology coupled with solar energy could provide greater efficacy to HALE aircraft because the closed loop system ensures long endurance and lightweight, furthermore hydrogen production and use cost has decreased in recent years.

In this work a strategy was developed to size, in an easy way, a solar/hydrogen system for HALE aircrafts. In the energy balance, different parameters can be considered, for example: solar radiation, efficiency of proton exchange membrane and photovoltaic technology, aircraft aerodynamic characteristics,