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EUROPEAN FUEL CELL

PROCEEDINGS

OF THE 7TH EUROPEAN FUEL CELL PIERO LUNGHI CONFERENCE

12-15 december 2017 / **NAPLES**

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UNIVERSITÀ DEGLI STUDI DI PERUGIA

UNIVERSITÀ DEGLI STUDI DI NAPOLI "PARTHENOPE"

ATENA
FUTURE TECHNOLOGY

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To Piero Lunghi. We miss you a lot.
To you our gratitude for ever.

This book is dedicated to the memory of Piero Lunghi, creator of the European Fuel Cell Technology and Applications Conference, dear friend and colleague, who prematurely passed away in a car accident on damned November 9, 2007.
Piero made significant contributions in the field of fuel cells in the course of his too short career. He was the leading figure in the formation of the fuel cell research group at the University of Perugia and several activities and research projects initiated by him are still ongoing. This means that, thanks to Piero, many young people are working in this exciting research field and are coming to Naples to present their results. Therefore, Piero's memory is in the conference name but Piero's contribution is still in the contents of this book.
The memory of our friend Piero, his great personal generosity and energy, survives in our hearts, his contribution and his tenacity survive in the work of young people who carry on his vision throughout the world.
This year three best paper awards have been established in memory of Piero Lunghi, following his ideas and his actions "Plan as if you should live forever and work as if you should die tomorrow". The prize that has been made possible by his parents and his sister, Paola, aims to be a message to young researchers everywhere: your ideas, your projects can change the world.
Give them your passion, your strength, and make all necessary effort to realize them. There is no greater satisfaction than seeing one's ideas become reality and become part of the future of our world. Piero strongly desired this, and constantly followed this through with conviction, passion and dedication.
For a better future, we need young researchers of this kind.

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FUEL CELL BASED-ON POWERTRAIN TO HYBRIDIZE SMALL UNMANNED AERIAL VEHICLES

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***Abstract* - The proposed investigation aims at increasing the endurance of a small unmanned aerial vehicle (UAV) where the power request for propulsion can be satisfied by means of a battery and a fuel cell. The hybrid configuration allows the required power to be obtained at take-off and the fuel cell to support the battery in order to maintain the state of charge (SOC) in the other phases of flight. This operating mode avoids deep discharging, when the battery SOC falls down a suitable threshold, and overcharging, which exposes to risk of explosion in case of lithium batteries. The cost of adding different capacity batteries was evaluated in terms of the increase of mass and consequently decrease of endurance. The power split was conveniently defined at take-off to prevent from excessive hydrogen consumption and to maximize the endurance with respect to the non-hybrid configuration in which the only fuel cell is used.**

Index Terms – gaseous hydrogen cells, lithium batteries, hybrid unmanned aircraft, indirect environmental impact.

I. INTRODUCTION

Fuel cells can be used to extend the range of small unmanned aircraft because electric power systems only based on batteries are characterized by low energy density and offer endurance that varies within the interval from about 60 to 90 minutes [1]. Polymer electrolyte membrane (PEM) fuel cells are appropriate to generate electrical power on board because of their low operating temperature and high energy density [2]. Lithium batteries are generally preferred because they have greater power-to-weight ratio among the available storage system technologies [3]. Some literature works concern with the comparison between battery and fuel cell technologies for electric aircraft and they mainly consist of correctly estimating the endurance [4-6]. The indirect environmental impact for hydrogen production from methane reforming reaction can be evaluated by [5]. The aim of the proposed investigation was to design a hybrid electric power system for a UAV, with mass of 10 kg, including airframe, motor, propeller and control board but excluding the source of power. The wingspan is 5.2 m and the lift over drag ratio is 17. The UAV can be equipped with a PEM fuel cell, with a mass of 6 kg, including the tank, the fuel, the regulator and the cooling system. The fuel cell is characterized by 36 cells, operating at 55 °C, and it has a maximum operating power of 600W. The hydrogen is gaseous and compressed at 5000 psi in a tank with a capacity of 22 liters. In hybrid configuration, a lithium polymer (Lipo) battery is added and its mass is summed to the base mass of 16 kg. The considered battery has a nominal operating voltage of 22.2V, a maximum continuous discharge current of 25A and it can supply a maximum power of 630W. The curve of required power was defined by considering the flight profile of a similar fuel cell powered UAV [2] excluding high winds and scaling the power because of the changed vehicle mass according to [7]. The fuel cell slowly responds to sudden load and the battery can buffer the fuel cell from transient current demands. But this event does not occur for the considered mission data. The flight speed was about 33 m/s at cruise. The power to be delivered by battery and fuel cell was obtained by resorting to the backward approach for complex aircraft [8].

II. DESIGN AND MODELING

Different Lipo batteries were considered for the hybrid configuration with rated capacity from 8Ah to 16Ah. Their mass specifications are reported in Table I. If the UAV is equipped with the only fuel cell, it needs 560W at take-off and 300W at cruise [2]. When equipping with both fuel cell and battery, the take-off and cruise power increase with respect to the non-hybrid configuration because of the increased UAV mass as shown in Table I. At take-off both the battery and the fuel cell have to give power because the fuel cell alone is not able to satisfy the request. The take-off power to be delivered from the battery in splitting mode is $P_{batt} = \alpha \cdot P_{prop}$, where α is the splitting factor and P_{prop} is the required propulsive power.

TABLE I

MASS AND POWER SPECIFICATIONS

Rated capacity (Ah)	Battery mass (kg)	UAV mass (kg)	Take-off power (W)	Cruise power (W)
8	1.58	17.58	616	330
10	1.98	17.98	630	337
12	2.37	18.37	644	344
14	2.80	18.80	659	352
16	3.27	19.27	675	361

The remaining power is given by the fuel cell. This mode was imposed for the first 100 minutes in order to cover up the take-off. In this phase of flight, the battery is discharged up to 60% of the SOC to safeguard the battery life. The fuel cell allows the battery to be recharged after that the fixed time of 100 minutes is elapsed so as to restore the initial capacity. While providing for recharging, the fuel cell satisfies the goal of propulsion. When the SOC reaches 100%, that is the full charge, the working mode switches from fuel cell to battery. In this way, the battery becomes the unique source of power as long as its SOC is over 60%. The fuel cell becomes again operative for recharge and propulsion when the SOC approaches 60%. Therefore, the charge-discharge cycle goes on and the fuel cell is able to recharge if the hydrogen is available. When the UAV runs out of fuel, the fuel cell cannot continue to recharge and so the battery is discharged at the SOC of 20%. The endurance is set as the flight time at which this SOC value is obtained. The SOC and the fuel consumption were estimated as in [5]. The curves of SOC and available hydrogen for the 8Ah Lipo battery, with recharge current of 0.7C and α = 0.15 are shown in Fig. 1.

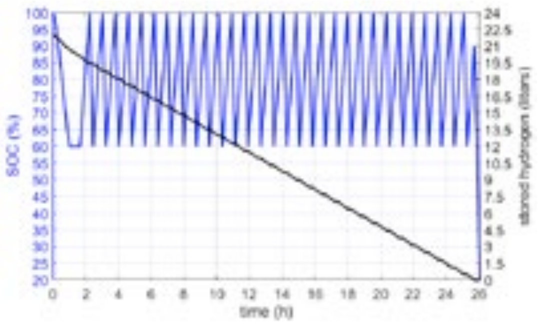

Fig. 1. Battery SOC and stored fuel

III. Simulation Results

A design of experiments was performed to evaluate the endurance when changing the capacity of the battery, the recharge current and the splitting factor between fuel cell and battery. The results are shown in Table II. The configuration of Fig. 1 with the best setting shows an endurance of 26.1 h, greater 8% than the value obtained in case of non-hybrid configuration, which turns out to be of 24.2 h. A sensitivity analysis revealed that α has to be suitably chosen because a greater or smaller value than the bounds given in Table II entails an unfeasible configuration.

TABLE II
ENDURANCE VALUES (IN HOURS)

	α	0.1C	0.2C	0.3C	0.4C	0.5C	0.6C	0.7C	0.8C	0.9C	1C
8Ah	0.1	23.9	24.2	24.4	24.7	25.0	25.2	25.3	22.7	20.6	16.6
	0.15	24.6	24.9	25.2	25.4	25.7	26.0	26.1	23.3	20.9	17.0
10Ah	0.1	22.1	22.5	22.8	23.1	23.3	21.7	18.9	14.0	4.6	
	0.15	24.3	24.7	25.0	25.3	25.6	23.8	20.5	15.1	5.0	
	0.2	24.5	24.9	25.3	25.6	25.9	24.0	20.7	15.2	5.3	
12Ah	0.15	23.9	24.3	24.7	25.0	22.3	18.4	2.2			
	0.2	24.3	24.8	25.2	25.5	22.7	18.7	2.2			
14Ah	0.15	23.0	23.5	23.9	21.7	17.3	6.3				
	0.2	24.1	24.6	25.0	22.6	18.0	2.7				
	0.25	24.3	24.8	25.2	22.9	18.1	2.4				
16Ah	0.2	23.7	24.2	24.2	19.0	6.7					
	0.25	24.0	24.5	24.6	19.2	6.8					
	0.3	24.1	24.7	24.7	19.3	6.8					

IV. Conclusions

A hybrid electric power system was designed for a UAV and the endurance values were compared for different Lipo batteries. The best endurance was obtained for low capacity battery and the recharge current had to be reduced at increasing the capacity. The use of fuel cell is crucial because a fast battery discharge occurs at take-off and the UAV is not able to complete this phase if equipped with the only battery.

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