Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 9, S. 292-298, 2, 2025
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Araştırma Makalesi

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 9, pp. 292-298, 2, 2025
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Research Article

IJANSER
https://as-proceeding.com/index.php/ijanser
ISSN:2980-0811

Minimization and Fuel Economy of Hybrid Fuel Cell Electric Systems Based on Conventional Energy Management PI (Application for an aircraft)

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(Received: 13 February 2025, Accepted: 17 February 2025)

(2nd International Conference on Recent and Innovative Results in Engineering and Technology ICRIRET, February 11-12, 2025)

ATIF/REFERENCE: Saadaoui, F. & Sereir, B. B. (2025). Minimization and Fuel Economy of Hybrid Fuel Cell Electric Systems Based on Conventional Energy Management PI (Application for an aircraft). *International Journal of Advanced Natural Sciences and Engineering Researches*, 9(2), 292-298.

Abstract – With the transition of the aviation industries to more electric aircraft (MEA), there is an increase in the maximum electrical load observed by the main and emergency generators compared to traditional aircraft. Therefore , the aircraft emergency system, consisting of an air turbine or air driven generator (ADG), is highly concerned about the need to meet energy demand in critical situations, especially at low speed where the power delivered is extremely low. Many aircraft manufacturers are considering an alternative to replacing the air turbine with a hybrid fuel cell system, combined with various sources.

The proposed model of the hybrid system of a more electric aircraft is implemented under MATLAB / SIMULINK in order to simulate and study an energy management strategy known as the classic PI in order to show the different behaviors of the power of a more electric aircraft according to the variations of the fuel cell power and the SC power, as well as the SOC of the battery, the fuel consumption and the DC bus voltage.

Keywords –MEA—Hybrid system— PEMFC— Classical PI strategy—SC—SOC.

I. INTRODUCTION

This research suggests an approach to reduce hydrogen fuel use and minimize costs in an electric hybrid system. An effective energy management policy is essential to ensure the stable and sustainable operation of hydrogen hybrid electric aircraft, which judiciously balance the objectives of fuel economy, battery life and fuel cell durability. Deterioration processes of the battery and fuel cell under extreme operating conditions are taken into account ([1], [2]).

A comprehensive assessment set is put in place, including models of degradation and energy use , to serve as a reward for deep reinforcement learning. The goal is to find a balance between fuel economy and the longevity of energy sources. The conclusions of the simulation indicate that the suggested conventional PI method decreases the deterioration of the fuel cell by 20% and that of the battery by 70% compared to other conventional strategies, under the standard conditions of a real-time application [2].

This study highlights the importance of the suggested PI model to ensure the reliable operation of traditional PI, while providing better performance and lower cost [3].

The air transport sectors are particularly interested in developing efficient and environmentally friendly propulsion systems , such as hydrogen vehicles that are actually used in cars, buses, trains, trams and even aircraft. These devices are capable of producing electricity with high efficiency, low noise and almost no emissions. This is why many aircraft manufacturers are moving towards the idea of a more electric aircraft (MEA), which allows the replacement of certain components of mechanical, hydraulic and pneumatic systems by electrical systems. This leads to several changes in the on-board networks, as well as in the section of the electrical network used as backup ([4], [5]).

It is envisaged to hybridize different sources of different nature to take advantage of the specific characteristics of each. The hybrid model discussed in this paper incorporates a PEMFC hydrogen cell, lithium-ion batteries and super-capacitors, as well as the corresponding converters ([6], [7]).

II. PEMFC HYBRID SYSTEM COMPONENTS

A. PEMFC system

In the automotive field , the proton exchange membrane fuel cell (PEMFC) is the most frequently used. One of the major assets of PEMFCs is their ability to operate in a low temperature range, ranging from -20 to 100 degrees Celsius. This indicates that start-up times are short, allowing the fuel cell to transition quickly from a low-load operating state to a full-load operating state. As illustrated in the figure. 1, the fuel cell uses hydrogen in gaseous form (the fuel) and air (the oxidizer) ([10], [11]) :

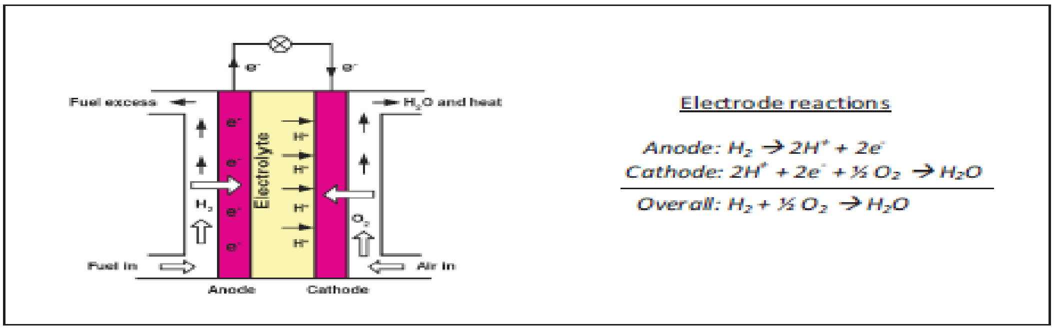
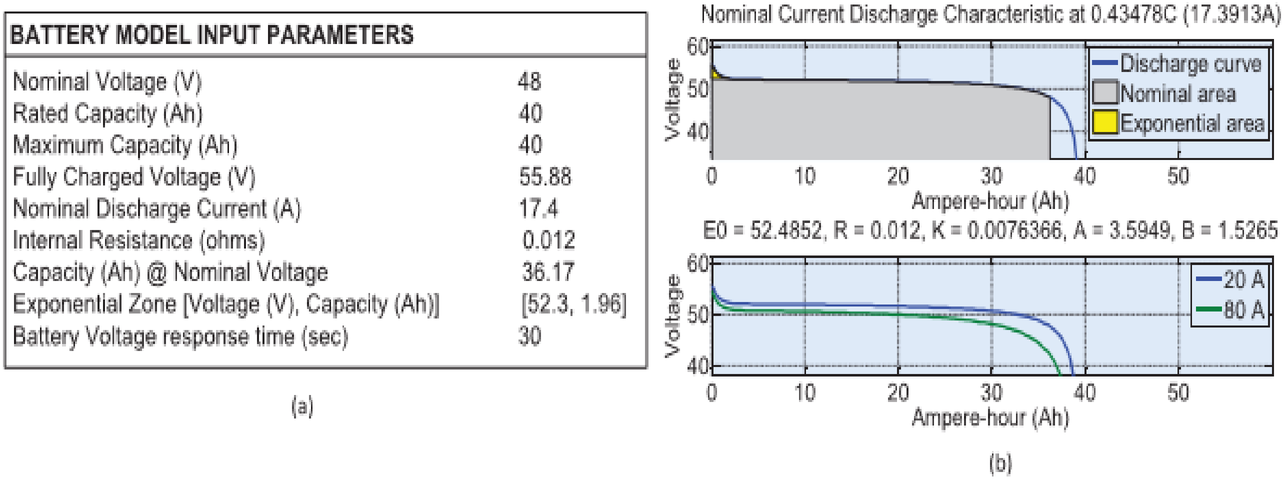


Fig. 1 Fuel Cell Model

B. System Lithium-Ion Battery Packs

The characteristics of the electric model of lithium-ion batteries frequently deployed in the industrial sector. This model integrates an internal resistor with a parallel RC network and consists essentially of three fundamental components : the open circuit voltage U_{oc}, the intrinsic resistors and the three analogy values of the capacitors. This model is prized because of the benefits offered by lithium-ion batteries, such as their large storage capacity, high operating voltage and increased longevity. These characteristics make them more favourable compared to other energy storage technologies for various applications [12].



BATTERY MODEL INPUT PARAMETERS

Nominal Voltage (V)	48
Rated Capacity (Ah)	40
Maximum Capacity (Ah)	40
Fully Charged Voltage (V)	55.88
Nominal Discharge Current (A)	17.4
Internal Resistance (ohms)	0.012
Capacity (Ah) @ Nominal Voltage	36.17
Exponential Zone [Voltage (V), Capacity (Ah)]	[52.3, 1.96]
Battery Voltage response time (sec)	30

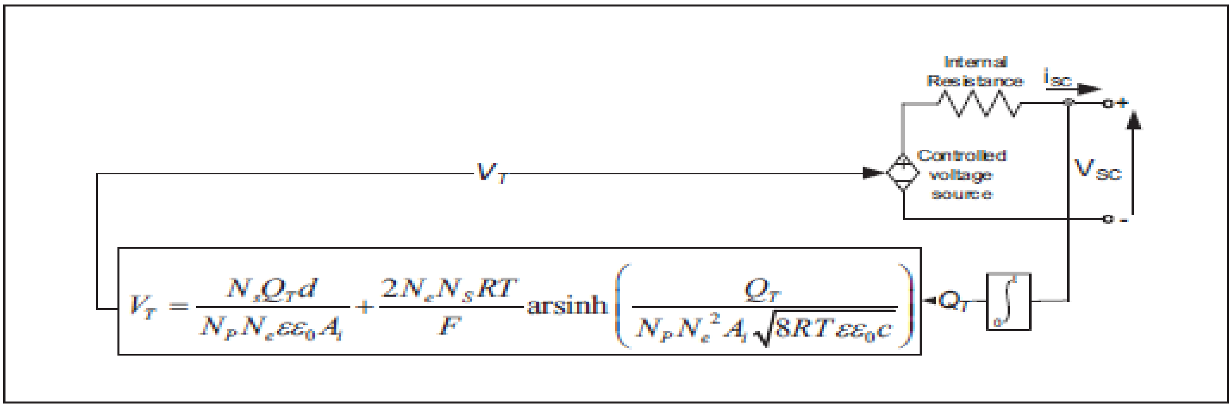
(a)

(b)

Fig. 2 Lithium-Ion battery (a) Input parameters (b) discharge curves

C. System Super-capacitor Packs

Super-capacitors, although they can deliver large currents and have increased longevity, often have a lower energy density than batteries. The super capacitor is a conceivable device for the accumulation of electrical energy in order to deliver power peaks over a short period of time (from a few seconds to a few tens of seconds), thanks to its fast charging and discharging capacity compared to the battery [13].



$$V_T = \frac{N_s Q_T d}{N_P N_e \varepsilon\varepsilon_0 A_i} + \frac{2 N_e N_S R T}{F} \operatorname{arsinh}\left(\frac{Q_T}{N_P {N_e}^2 A_i \sqrt{8RT\varepsilon\varepsilon_0 c}} \right)$$

Fig. 3 Super-capacitor model

III. HYBRID PEMFC SYSTEM

The hybrid power system is developed taking into account the power and energy requirements for a standard emergency landing scenario. In this research, a typical emergency landing sequence figure 4, provided by aicraft aerospace is considered for each analysis. In the event of loss of the main generators, the avionics and APU batteries provide power to the critical loads for approximately 20 seconds, until the RAT takes over. When the RAT is activated, the batteries are deactivated and the heating/braking control devices light up in preparation for landing [14].

Thereafter, the flap/ batten and landing gear are set in motion. As the aircraft approaches the landing, its speed drops below 147 knots and the RAT disengages. Then, over the course of 20 seconds, the RAT tries to recover when subjected to a reduced critical load. Subsequently , upon landing the aircraft, the RAT's power drops to zero [14].

Those five minutes. The landing cycle illustrates the behaviour of the RAT in a critical situation . However, in practice, the aircraft may require the RAT not only for approach and landing, but also during the cruise phase. In other words, the RAT may need to provide energy for 0.5 to 4 hours. As part of this research, the elements of the hybrid power system are chosen on the assumption that the emergency system will operate for thirty minutes. The emergency load profile envisaged is taken from figure. 4 and extends over a period of 30 minutes, in accordance with the flight scenario [15].

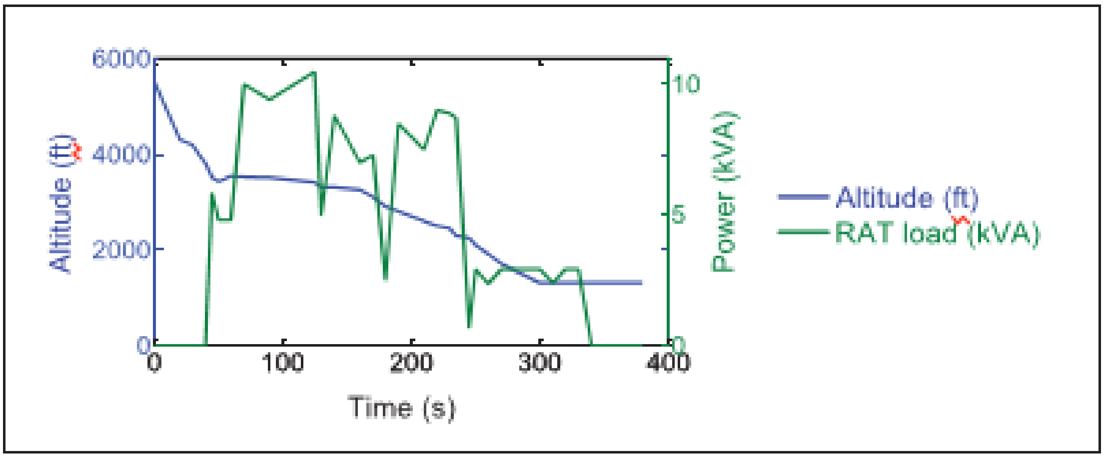


Fig. 4 RAT power for 5 min. emergency landing [16]

Table 1. Hybrid system power/energy requirements [16]

COMPONENTS	POWER/ENERGY REQUIREMENT
FUEL CELL SYSTEM Continuous power	 7.5/0.8 = 9.375 kW
BATTERY MODULES Maximum power Usable energy DOD Total energy content	 (10.5 - 7.5)/0.8 = 3.75 kW ((8.5 - 7.5)/0.8 x 30 x 60)/3.6 = 625 Wh 30% 625/0.3 = 2.08 kWh
SUPERCAPACITOR MODULES Peak power Usable energy DOD Total energy content	 10 kW (10000 x 5)/3600 = 19 Wh 30% 21 Wh

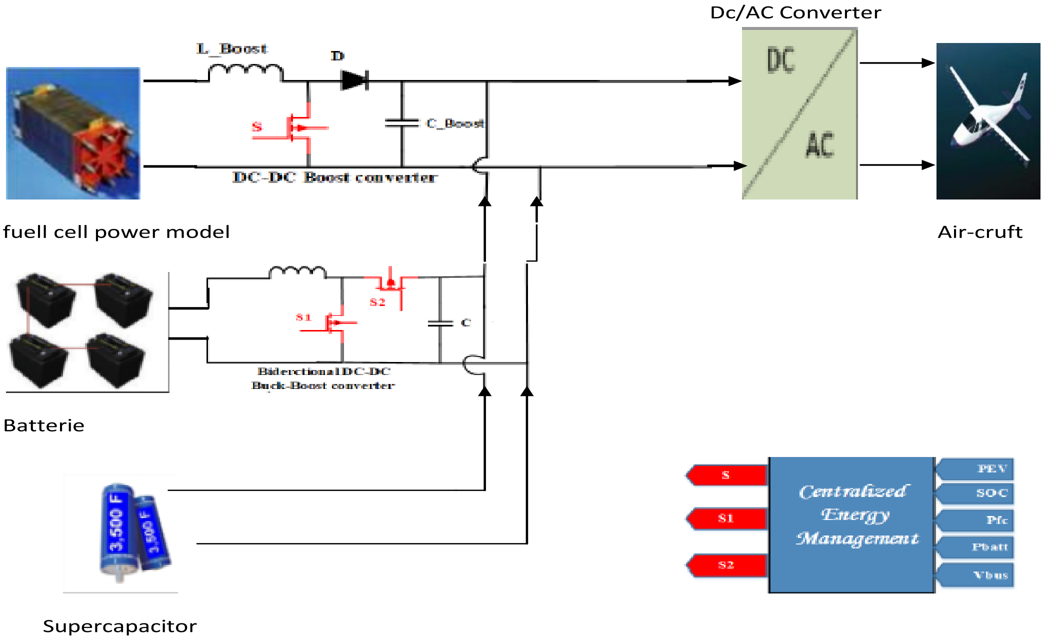


Fig. 5 PEMFC Hybrid System Diagram for Air-Graft

IV. RESULTS AND DISCUSSIONS

Figure 6, illustrates fifteen (15) specific states representing the different variations of the load, can be grouped following five important phases taking into account the variation of the PEMFC.

Initial phase : Following the observation of these results, we noticed a significant stress in terms of electrical power required for charging at start-up during this phase ranging from t=40s to t=140s (period when the system is in transition). This justifies the starting torque of the various electric motors integrated into the hybrid system, that is , in this situation, the supercapacitor and the battery support the fuel cell, providing the necessary energy that is lacking due to the late response of the fuel cell.

Second phase : Once the power demand at start-up is exceeded, we observe a decrease in the necessary power, or the battery remains stable and the super-capacitor is supplied with the residual energy of the fuel cell which gradually decreases, reaching a minimum power restricted to 2.6KW and thus generating the first warning signal . Subsequently , the electric aircraft descends into another transient state between t=140 s and 170 s.

During the third stage : The speed of charging increases from t=170 s to 245 s, reaching its optimal power of 9KW after a transient phase, resulting in a second critical state in the PEMFC. During these steps, the SC power is at zero, however, the battery tries to provide some power to support the fuel cell.

Step Four : At t=245s, the aircraft drops again from 9kW to 1KW, resulting in a third critical failure at the PEMFC. Due to this decrease, the power of the fuel cell meets this need thanks to the supercapacitor and the battery which, once fully discharged, will be charged. After 15 seconds, the aircraft enters a stable phase, i.e. between 155 and 240 seconds, in order to prepareit for landing. Thus, to meet this requirement, the fuel cell reduces its continuous powerfrom 7.3 KW to 4.6KW, which is the rated power.

However, in this situation, the electric aircraft requires less power than the fuel cell and battery. The supercapacitor provides a positive or negative response to each rapid change in speed (acceleration, deceleration and braking) or resistance torque (inclination, slope) in order to guarantee the stability of the aircraft.

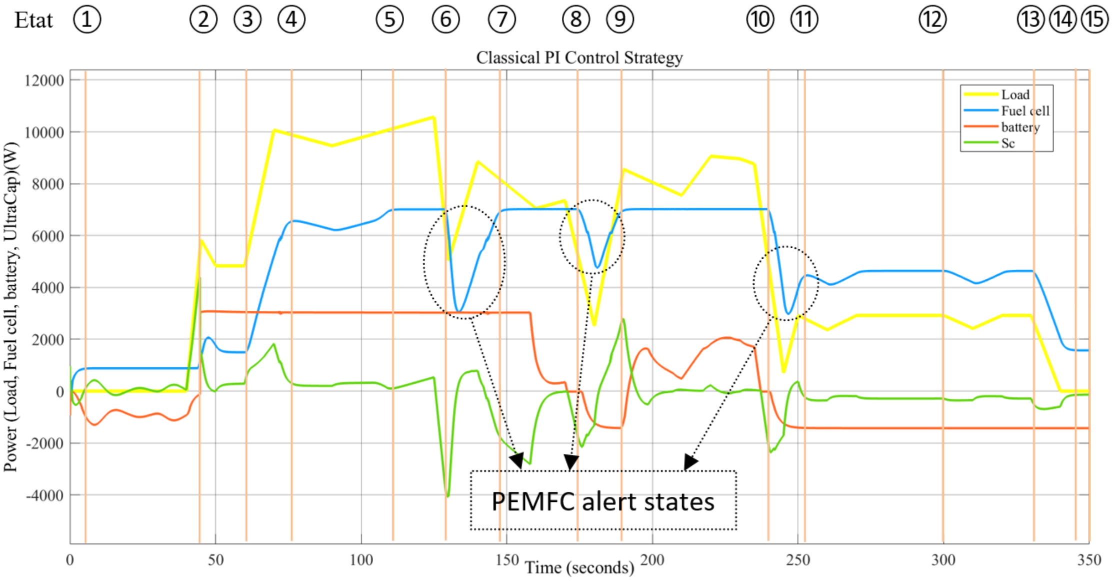


Fig. 6 Power curves by classical PI strategy

In the fifth phase: At t=255 s, the steady state of this stage begins. Here, the super-capacitor assists the fuel cell by about 1 to 2 KW to power the load, then it returns to zero and the surplus is used to charge the battery. The required power of the PEMFC is reduced from 4.6KW to 2.6KW due to the slowdown of the aircraft. The fuel cell provides the energy required to satisfy this demand (battery discharge).

Finally, during this step, a decrease in the required power is observed until reaching a minimum level of 2KW for the fuel cell, thus characterizing the rapid slowdown of the electric aircraft. It is then obvious that the power required is less than that produced by the fuel cell. Thus, the battery is recharged using the remaining energy. The supercapacitor alsoprovided additional power during any rapid fluctuation .

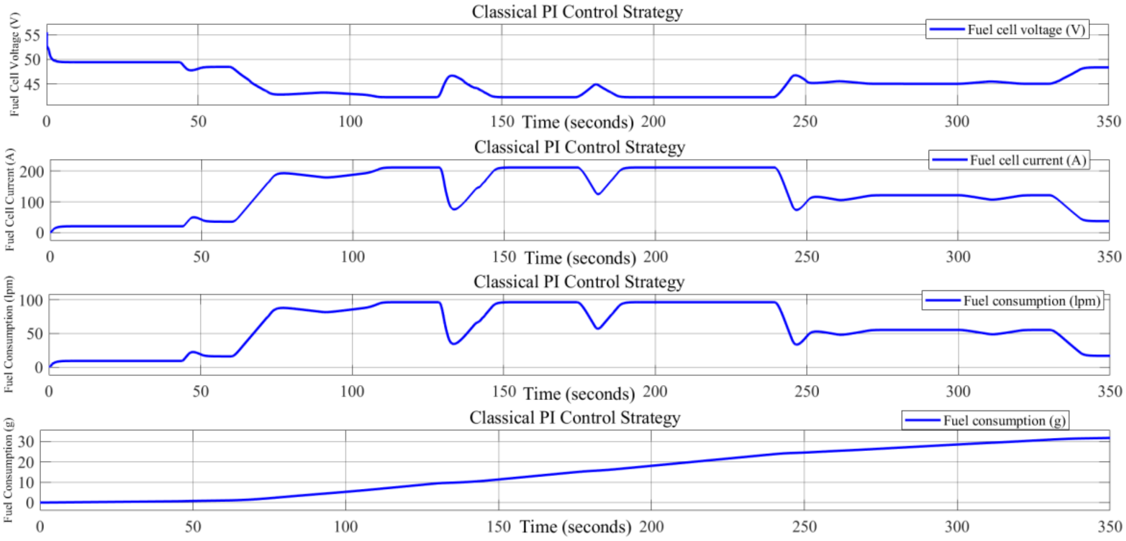


Fig. 7 Voltage , current and fuel consumption curves of the fuel cell by conventional PI strategy

It is easy to see that fuel consumption (g/s) almost follows a linear trend as a function of time, especially between t=45s and t=300s. This means that the greater the demand for feedstock , the greater the need for hydrogen (in grams). Figure. 7, illustrates fuel consumption relative to air. An increase in consumption has been observed whenever the power required increases, however when the power drops during an alert, fuel and air consumption is reduced. The maximum fuel consumption is 100 liters per minute.

V. CONCLUSION

Energy management is essential to optimize the overall efficiency of hybrid systems, minimize fuel use and preserve the performance and longevity of each element.

In this study, active energy control by conventional PI was performed using DC/DC converters. The purpose of the energy management of this hybrid system is to minimize the use of hydrogen. At the same time, it ensures that the state of charge of the battery (SOC) remains within the desired terminals.

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