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Energy Management for Fuel-Cell/Battery Hybrid
Power source of Unmanned Aerial Vehicle.

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DEDICATION

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DEDICATION

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General introduction

General Introduction

Energy is defined as the ability to do something, and is found in several forms all related to movement, and can be transferred energy from one body to another and from one form to another, where it is classified based on the new form to which it has been moved, and can be converted energy from one form to another using many different methods, for example can be used many different devices such as generators, fuel cells, batteries, thermal engines to burn fuel in the production of electric power, or mechanical usable, human needs need energy at all times, it is He uses it continuously in all aspects of his life.

Energy and environmental problems are closely linked because it is almost impossible to produce, transport or consume energy without significant environmental impacts, and environmental problems increase with energy use.

Developed countries are therefore seeking to provide the latest research on clean, environmentally friendly energy sources available, especially as the global global warming problem worsens.

Fuel cells are one of the most environmentally friendly means of generating energy, and therefore they are of great interest in their future development and use in the operation of cars and the supply of electricity to homes. This type of eco-friendly fuel is a good alternative to the current fuel used in conventional transportation.

New energy sources such as solar and hydrogen have been applied to unmanned aerial vehicles (drones), which can be formed as hybrid energy sources due to the miniaturization, lightweight, environmental protection issue for drones.

Hybrid power has used electric propulsion technology in drones, and it imposes this trend of evolution into a hybrid-powered system in order to achieve a long mission endurance journey and improve the energy efficiency of drones, and many research work focuses on managing

The on-line power management strategy can improve the distribution of bioelectric power as it directly affects the efficiency and fuel economy of the on-board hybrid system.

In order to give the guiding principle of this emerging technology to UAV the theme highlights the optimal energy management strategies for drones.

General Introduction

In the **first chapter** we will address the state of the art of uavs and fuel cells and batteries .

In the **second chapter** we will talk about the dynamic and modelling of the energy sources uavs,

The **third chapter** contains energy management strategies for energy sources, we also presented the Stratigatin, frequency and the fuzzy logic control , finally we presented the simulation results.

At the end of this work ,a general conclusion is then given as well as some recommendations for the present work and the future development .

Chaptre I

- State of the art on Fuel Cell
UAVs

I.1.Introduction

The objective of this chapter is to present a state of art about drones and on hydrogen fuel cells.

In the first part of the chapter, we will address the definition of unmanned aerial vehicles, their history, origin, types, fields and composition. Then, the second part will present the most important component of unmanned aerial vehicle equipment the power source.

It has become one of the modern innovations of energy sources for drones, hydrogen fuel cells, where it has become known as the fuel of the future.

I.2.Unmanned Aerial Vehicles (UAV)

I.2.1Definition

Unmanned Aerial Vehicles (UAV) may be loosely described as an aircraft without a pilot onboard. An UAV may be piloted remotely via radio control or fly autonomously using an onboard autopilot system. In some cases, both forms of flight control are present. That is to say radiocontrol is present in addition to an onboard autopilot system. Refining the definition of a UAV, a propulsion system must also be present onboard the aircraft [1].

A propulsion system may consist of a motor with a propeller or a jet engine. This second requirement excludes flying projectiles such as bullets and artillery shells. Typically, the term UAV implies a powered unmanned aircraft, either fixed wing or rotary wing

I.2.2History

Drones have been around ever since before the first manned flight Wright Brothers in 1903. The first drone flight was recorded in 1896 when Samuel Langley launched a steam drone from a home boat with the Potomac River on board.[1]

The plane flew for 90 seconds and covered a distance of 1005 meters. The engine consists of a cylindrical steam engine. The development of the drone is closely related Navigation and wireless navigation technologies. During the period from 1917 to 1918, both the United States and the U.S. Navy(United States Navy) and Army funded the drone programs to deliver the decree to remote targets. Navy The military's "torpedo" and "Kettering Bug" were tested with varying results. By 1924, the Naval Research Laboratory had shown the success of a radio-controlled aircraft flight. The importance of this test

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flight was that a plane was remotely controlled during all stages of the flight (Keen, 2013)[1].

The Navy subsequently sponsored the development of a drone based on a carrier under the joint drone combat system program. With over a decade of development, the J-UCAS TDR-1 program has produced an attack drone (Gundlach, 2014).

The Navy was considered the first operating drone of combat missions during World War II.

TDR-1 is powered by Lycoming O-435 twin internal combustion engine.

The avionics systems on board the TV transmitter included a radar altimeter and a remote control receiver (Lee, 2013).[1]

An important factor for success TDR-1 can be credited to improved navigation and radio control electronics.[2]

1.2.3 Market

The current day market for UAVs is expanding, but the sector of small Unmanned Aerial Systems (UAS) has the largest growth potential. The designation of UAS instead of UAV includes not only the airplane platform, but also the control and analysis equipment needed to perform the mission objectives. The classification of “small” UAS is generally accepted as UAV weight under 25 kg. The UAV is not valued on the novelty of a remote controlled aircraft, but rather on the value of the mission it can perform. In other words, the value of the UAS is in the capabilities it provides to the customer. For example, military UAVs perform intelligence, surveillance, and reconnaissance (ISR) missions. The airplane platform includes imaging and navigation equipment to record imaging and location data. The full UAS system includes the UAV plus radio control equipment and analysis computers to interpret the data. The value of the UAS is in the ability to gather imaging data with associated locations of a remote area. Similarly, the value of a civilian UAS may be to provide thermal imaging data of crops over a group of large.[2]

As the cost of UAS decrease, the variety of applications broadens and the user base expands. During the early years of UAV development, demonstration of the technology was the goal. The users were researchers and financiers. Although research and development costs were high, they were acceptable to demonstrate proof of concept. After reliable service had been proven, military and government sponsored programs were the only users; the only ones who could afford the costs. For these end users, UAS applications were mainly military, namely ISR and weaponry. As the technology matured, scientific

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programs were funded, such as the Altair program. Continued development and innovation have now decreased the costs to the point where commercial applications are possible. Scientific and civilian flight missions that are considered dull, dirty, or dangerous are good candidates for UAS applications. Areas of interest such as earth science, land management, communications, and homeland security are being considered (NASA, 2016).[1]

To continue the trend of increased UAS mission capability at a lower cost, further improvements to the technology are being researched. Topics such as cost, flight endurance, flight autonomy, sensor systems, and application data analysis are areas which will have a significant impact on sUAS market growth.

I.2.4 UAV types

It is divided into two types in terms of the control mechanism:

➤ Ground control station

It is the pilot who provides the plane with coordinates and information through the command base on the ground, whether it is fixed or mobile, and the plane is contacted by satellite.

➤ Automatic launch and recovery

Where the plane is provided with coordinates and information in advance before take-off, including the way to go and return and carry out the mission without a process of contact with the base.

I.2.5 UAV Hybrid Power Systems

Within the UAS category, drones that weigh 10 kg or less often use electric motors such as a power plant. There are many advantages to using a small electric motor drone scale. Electric motors have higher efficiency than their counterparts as they have efficiencies in the range of 80% to 90%. Since there are fewer moving parts, electric motors are more reliable and easier to maintain. Electric motors have no emissions; Zero carbon footprint. Also, electric motors are low noise, vibration and thermal signature. The disadvantage of electric motors is electrical energy storage. Due to the limitations of battery technology, the carrying capacity is limited. With only battery power, typical flight times are three hours or less. There is great interest in the drone community to extend the endurance of an electric powered flight.[1]

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Several methods have been used to improve the durability of small drone exercises, including two methods. The first approach is to install photovoltaic cells on the plane to generate electricity while flying. The second approach is to use fuel cells to convert stored hydrogen into electrical energy.

In this work, the focus will be on the fuel cell approach. In many cases, the energy provided by the fuel cell is not sufficient for the plane to take off or climb. To compensate, the batteries are combined with the alternative power source to create a hybrid power system. In other words, battery power is used to increase the delivery energy of a fuel cell during takeoff or flight altitude where the pilot can accelerate to the best rate of climb speed, where the aircraft will gain the most altitude in the least amount of time.[1]

An example is a prototype aircraft constructed at the University of Johannesburg in 2009. A typical small Piper Cub model aircraft was powered by a dedicated 100-watt fuel cell. The wings of the Piper Cub are 2.31 m and weigh 5.35 kg. The main objective of the project was to demonstrate that a small 100-watt fuel cell could be sufficient for flying power during the level flight. To get enough energy while taking off and climbing, lithium Polymer batteries were used. The wireless control transmitter has one dedicated channel control relay inside the aircraft to switch between batteries or fuel cell. While taking off climb the batteries electric motor. When the flight level or part of the flight started to fly the power source from the batteries was transferred to the fuel cell. Although the trip lasted only 9 minutes, the project goal was successfully presented .

The use of fuel cells with batteries in drones is synergistic or complementary in quality. Hydrogen fuel cells have a relatively.

On the other hand, the batteries have a relatively.

Fuel The cell can enhance endurance while providing the battery with high power when needed. Fuel cells extend endurance due to the high energy density of hydrogen. Compared to gasoline, pressurized hydrogen gas contains more than 2.5 times the specified energy. For the same amount of fuel weight, compressed hydrogen stores more than 2.5 times the energy of a gasoline.[1]

In addition, ideally the high energy density of compressed hydrogen and the high efficiency of fuel cells can result in a 7.5 or more times greater endurance. It is the potential increase in aviation's endurance that has attracted interest and research in hybrid

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fuel cells and battery power systems for small-scale drone applications. Actual flight endurance improved below ideal value due to practical engineering issues such as weight, power management, fuel cell system design, hydrogen storage, and other system-level design problems.[2]

I.3 UAV Power Management

Hybrid fuel-cell power management and battery power systems in unmanned aircraft applications control the flow of energy to and from each power source[20]. The goal of the Power Management System (PMS) is to increase durability while keeping both the fuel cell and the battery within safe operating limits. In general, different energy management approaches may be classified into two broad categories, active and passive[21].

Passive Power Management (PPM) cases where the fuel cell and battery are chosen to be approximately the same voltage directly connected in parallel. The collected energy is then sent to the electric motor to power the aircraft. The advantage of PPM is that there are no additional electronic devices to carry on drones; weight is kept to a minimum. The drawback of PPM, is that there is no power flow control in the system[20]. There is no mechanism to ensure that the fuel cell and battery work within its limits. If there is a voltage mismatch between the fuel cell and the battery, then the energy loses the unmanaged energy flow between the two sources. In these cases, the two energy sources are said to be in conflict[20].

The second category, Active Energy Management (APM), uses electronics to control the system's energy flow. Fuel and battery cells are kept within operating limits. The downside of APM is that there are supervisory carry electronics for drones, thus increasing the weight and power consumed. The APM system can be as simple as using a relay to control any of them.[1]

The Piper Cub example mentioned earlier is a good example of a simple APM approach. A useful feature of the Piper Cub APM method was the weight and power consumption of APM was minimal. Only one relay and channel of the radio are used. The disadvantage is that the distant factor must know when to switch energy sources. The APM system can be quite complex as many DC-to-DC converters are controlled by microprocessors. In these cases, the energy flow can be closely controlled, optimized and managed results. The cost of this control is the extra weight, cost, and power consumption.

I.4 Energy Storage Systems

With the technological development of drones, then the source of electrical energy for these planes was developed from conventional batteries to that operate as fuel cells.

I.4.1 Fuel Cells FC

I.4.1.1 History

Fuel cell technology was invented in England in the mid-nineteenth century by William William Grove. More than 160 years ago, he did not know that his invention, which he developed in the year 1839 AD, would solve a problem facing the world in the twenty-first century to discover fuel cells that Through which it is possible to obtain electricity from hydrogen or alcohol without any combustion process, and by this it has solved the difficult equation, which is obtaining clean energy without polluting the environment and at the lowest prices.[2]

The solution lies in this small cell called the fuel cell, but due to the uselessness of its use in that period, this invention has been locked in drawers for more than 130 years, but fuel cells came back to life in the sixties, when General Electric developed cells Working on generating the electric energy needed to launch the two famous spacecraft (Apollo) and (Jimny), in addition to providing clean drinking water, the cells in those two vehicles were large and expensive, but they performed their tasks without any errors, and they were able to provide an electric current as well A source of clean drinking water[8].

I.4.1.2 Definition

A fuel cell is an element that converts chemical energy in the fuel (be it hydrogen, natural gas, methanol, gasoline ...) and in the oxidizer (air, oxygen) into electrical energy. In principle, the fuel cell functions as a battery saver, but unlike the saver, the fuel cell does not empty and does not need charge, and generates electrical and thermal energy as long as it is fueled and oxidized[3].

Both fuel cells and savings are electrochemical elements, and both contain a positive (electrode) electrode and a negative electrode and an ionized conductor called an electrolyte medium. The fuel cells are classified according to the medium that they often contain. Electrochemical elements generate electricity without combustion of the fuel or oxidizer, as happens with traditional methods of generating electricity.

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The structure of the fuel cell is usually composed of a fuel electrode (anode) and an oxidant electrode (cathode) separated by an ion-conducting membrane. The oxygen passes on one electrode, and the hydrogen passes through the other electrode, generating electricity and water. The fuel cells combine the fuel and oxidant molecules without burning or generating pollution, as in inefficient and polluting generation systems that use conventional incineration technology.

I.4.1.3 Types of fuel cells

Fuel cells are generally classified into two basic categories, regarding types of electrolyte used and operation temperatures[4].

In the former category, five main types of fuel cells

- Electrolyte Membrane Fuel Cell or Proton Exchange Membrane Fuel Cell – PEMFC.
- Alkaline Fuel Cell – AFC.
- Phosphoric Acid Fuel Cell – PAFC.
- Molten Carbonate Fuel Cell – MCFC.
- Solid Oxide Fuel Cell – SOFC.

I.4.1.4 Electrolyte Membrane Fuel Cell or Proton Exchange Membrane

Fuel Cell – PEMFC

In the current state of technology, PEMFC is showing a relatively high level of development - a variety of different systems with these cells are already available on the market. Moreover, PEMFC operates in a temperature range below 100 ° C, which is suitable for application as a drone electricity source.

PEMFCs are fed into drones with hydrogen fuel, which must be stored or produced on board. A variety of hydrogen storage systems have been used, including gas pressure, chemical hydrate and cryogenic low-pressure liquid hydrogen tanks.

Unfortunately, the hydrogen content in the gaseous fuel produced by the repair process is large (for example a methanol vapor remodeling component of 75% of H₂), which reduces the efficiency of FC and peak power output[5].

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I.4.1.5 Definition of hydrogen

- Is the simplest element known to man on earth, representing more than 90% of the components of the universe and 30% of the mass of the sun, and is the third most available element[3].
- Hydrogen is a gas that has no color, taste or smell, which is non-toxic.
- Consists of a two-part atom H₂
- Hydrogen is a light element with high thermal value.

I.4.1.6 Principle of the hydrogen fuel cell

Low temperature fuel cells (200°C, 390 °F) act on hydrogen gas as fuel. At present, there is no easy and available source to obtain hydrogen in large quantities, in a short time, and in high safety. There are two ways to solve this problem. In the short term, conventional fuel can be used to generate the required hydrogen. Conventional fuel conversion to hydrogen is called fuel reforming. Steam reforming is an example where steam is mixed with conventional fossil fuel at an approximate temperature of 760°C. The chemical formula for the hydrogen reconstitution process of CH₄ mostly natural gas is given by the following formula:



Individual fuel cells can be combined to form a “stack.” The number of fuel cells in this stack is what determines the resulting tension, and the area of each cell determines the total current produced. The current current with the resulting tension gives the total amount of electric energy generated, according to the relationship[6].

$$\text{P} = \text{V} \times \text{I} \quad (\text{I.4})$$

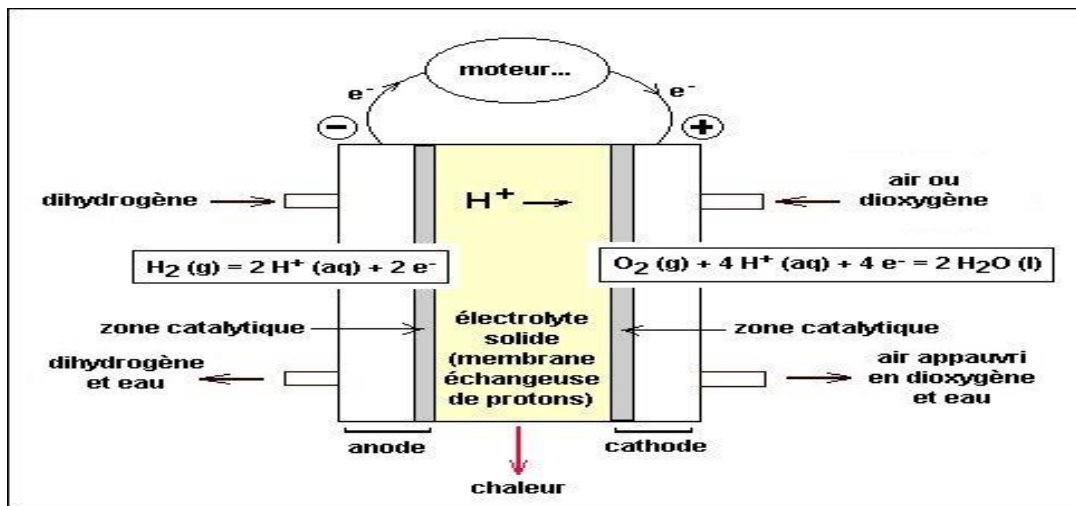


Figure (I.1) : Membrane Electrode Assembly

I.4.1.7 Applications of FC

Fuel cells were used initially in space applications and then began to develop and spread more in military circles, where fuel cells were then used as a backup source due to their high reliability. Currently all car companies are marketing their new hybrid products that use fuel cells in addition to the use of fuel cells, which is beginning to spread in buses, trains, planes and scooters.

Fuel cells have also spread in small applications such as cellular phones, laptop computers, and others. The possibility of using fuel cells to feed hospitals, banks and ATMs is being studied[3].

The fuel cells are installed in waste treatment plants to convert the methane gas they produce into electricity. Fuel cell applications are multiple and endless, and as technology evolves, its fields of use increase. The online reference provides monthly journals for all fuel cell applications in the world.

❖ Fixed applications:

Currently, 2500 fuel cell systems are installed worldwide, in hospitals, hotels, offices and schools, in addition to using fuel cells as electrical stations connected to the public electricity network to provide support for the network or independent electrical stations in areas that are difficult to link with the network[3].

When using fuel cells in a cogeneration system where the resulting thermal energy is used, the efficiency can be increased to 85%.

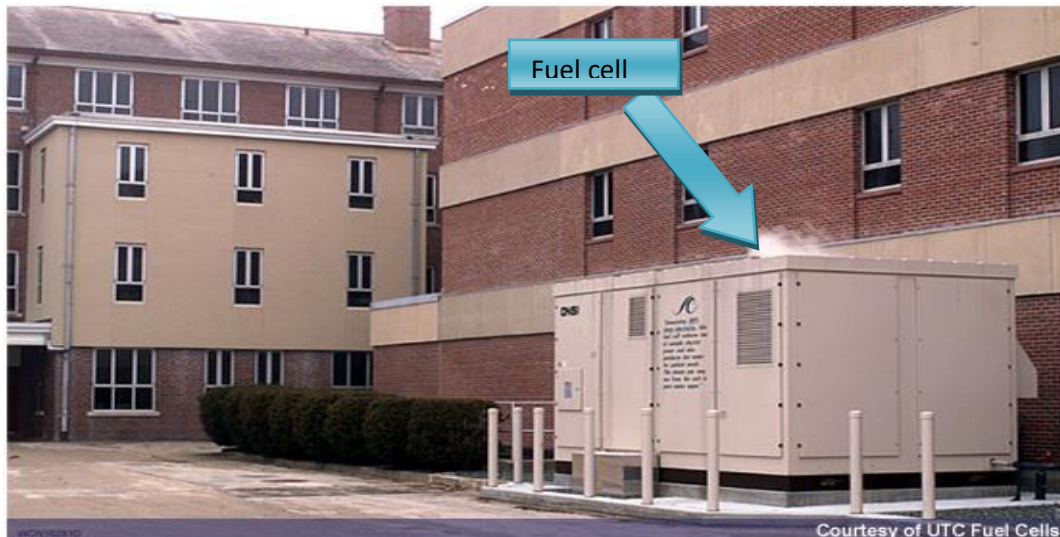


Figure (I.2) : Exemple Fixed applications

❖ Telecommunications

With the increased use of computers, the Internet and communication networks, a more reliable source as a source of nutrition has emerged, and fuel cells have proven 99.99% reliable. The savings can be replaced by fuel cells to provide a power of up to 5kW. They are silent and environmentally friendly and can be designed to be durable, that is, to withstand the ambient weather conditions. It is currently used as a main power source or as a support source in cell towers and telecom switch nodes.



Figure (I.3) : Exemple Telecommunications

❖ Waste and water treatment plants

Fuel cells are now installed in waste and water treatment plants all over the world, and this technology has proven its ability to reduce emissions by using methane produced from these sites as fuel.



Figure (I.4) : Exemple water treatment plants

❖ **Transportation**

-Cars:

All car factories today are working on developing new hybrid vehicles, often

It was supplied with fuel cells with conventional fuel, in addition to some of them were put on the commercial market.

Currently cars are powered entirely from fuel cells.

Daimler Chrysler and Toyota motors General It should be noted that General Motors Which constitutes about 40% of the total investments in the Daimler-Chrysler business In order to make the choice of (cell fuel) cars in the world to support the research of developing fuel cells[4].

Environmentally friendly rather than internal combustion engines, and the three companies have supported this research

About a billion dollars.[4]

-Buses:

During the past period, more than 50 buses running on fuel cells have been used in Europe and AmericaNorth, South and East Asia and Australia. The high efficiency of fuel cells in addition to pollutants very low, because hydrogen is produced from renewable sources, it has greatly improved the quality of air, especially in areas that are considered one of the most polluted regions in the world, such as China.

-Bicycles:

Despite their small size, many bikes are considered air pollutants, their exhaust gases are very polluting monoxide carbon when compared to their small size. It produces carbon

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monoxide in amounts similar to that of a diesel truck. So hydrocarbons and hydrocarbons that run on fuel cells are a suitable solution for countries like India and Asia where many residents use bicycles as a means of transportation.

❖ **APUs Units Power Auxiliary**

Advanced trucks carry many electrical appliances such as heaters, air conditioners, computers, telephones, refrigerators and microwaves. To run these equipment while the Department The truck is idle the engine must be running. The U.S. Department of Energy measures annual fuel and maintenance costs for a heavy truck as low as \$ 1,800 and at DOE Energy.

Saves 670 million gallons of APUs cell fuel using a fuel cell as a unit of diesel auxiliary electricity per year and 1 million tons of carbon dioxide per year.

❖ **Portable Power**

Fuel cells can provide us with energy as the electrical grid is not available as it is used in emergency situations and military applications. It is more efficient than batteries and works for a longer period and is lighter.

❖ **Micro Power**

Fuel cells are among the most suitable energy sources for small electronic devices due to their small size and their ability to generate a large amount of electric energy relative to the small size. Fuel cells are currently used in cell phones, laptops, watches and other small applications. The chargers on the market now can charge the computer for about twenty hours and the cell phone for thirty days. Also used in smoke detectors, alarms and surveillance cameras. Many of these installations are displayed annually at the FC EXPO fuel cell exhibition held in Tokyo annually. Last year, Sony launched a portable charger that is a hybrid device between a fuel cell and a lithium storage device[2].



Figure (I.5) : Exemple Micro Power

I.4.1.8 Advantages of fuel cells

The most important benefits of fuel cells:

- ✓ It gives a very high level of efficiency and safety compared to others.
- ✓ As a result of its ability to convert chemical energy into electricity directly; These cells are very efficient because they do not waste any of this energy.
- ✓ The maintenance process is very easy and simple, and it lasts for a very long time.
- ✓ It is used as needed, by controlling its size.
- ✓ Do not produce any pollutants; It also creates electricity and drinking water, so it is considered a clean source of energy[4].

I.4.2 Batteries

technology offers the highest energy density. rechargeable battery types such as nickel-cadmium (Ni-Cd), nickel metal-hydride (Ni-MH), lead acid batteries, lithium ion batteries are the best choice for UAV power systems.

Factors such as energy density, cell voltage, weight, volume, and discharge rate are primary considerations for battery type selection.

Secondary factors such as cost and charge retention are attributes to consider as well.

I.4.2.1 Types of batteries

- Lead Acid
- Nickel–cadmium Ni-Cd
- nickel metal hydride Ni-MH
- Zinc-Air
- Lithium ion Li-Ion
- Lithium Polymer LiPo

I.4.2.2 Lithium Polymer and polymer Battery

Lithium is the preferred anode material due to its high standard reduction potential and its low weight in higher energy densities of around 200 Wh/kg. With a nominal cell voltage of 3.7V, lithium ion batteries obtain higher battery voltages with fewer cells connected in series.

Higher voltage batteries need to supply less current to deliver the same amount of power. When a battery delivers less current,

then the amount of stored active chemicals within the battery lasts longer. The result is a relaxed

constraint on the amount of active chemical material stored within the battery to deliver a specified amount of energy. Due to the higher cell voltage of lithium ion batteries, fewer cells are required to obtain a desired battery voltage.

Less active chemicals need to be stored to reach a specified energy storage goal. The end result is lower battery weight and volume for lithium ion batteries as compared to other options.

Although battery cost is a factor, lithium ion battery cost is still low enough to be the popular choice of battery type in both the model airplane community and the UAV industry.

A Lithium Polymer (LiPo) battery is a type of lithium ion battery, but the name is used in two different ways. Within the scientific and industrial research communities, the name lithium polymer battery means a lithium ion battery where the electrolyte is a polymer.

A Lithium Polymer (LiPo) battery is a type of lithium ion battery, but the name is used in two different ways. Within the scientific and industrial research communities, the name lithium polymer battery means a lithium ion battery where the electrolyte is a polymer.

I.4.3 Design aeropack system uavs :

To conduct an unmanned aerial vehicle (UAV) design, which uses a fuel cell system. Special emphasis was placed on the electrochemical performance of the power unit under various operating conditions. Since the power unit consists of a set of fuel cells and a set of batteries, the energy reaction was carefully checked during the operation of the drive system[7].

Chapter I

I.4.3.1 Conceptual design of Uav:

In the beginning, we need to define the shape of the airframe and define the tasks that the plane should perform, as it is well established in the rules of flight and air dynamics that the strength of the four propellers is twice the weight of the plane in order to allow it to fly with a heavier weight than air and gain a certain height as the speed increases Motors. The airframe must therefore be affected by a force that reflects its power and lift produced by the propellers. Among these units that can be purchased, the most suitable power unit for the project is the AEROPACK fuel cell range produced by Horizon, a company from Singapore[7].

I.4.3.2 AEROPACK:

AEROPACK is one of many commercially available Horizon fuel cell systems that can be customized to fit a variety of platforms, expanding its range to deliver up to several kilowatts of power, making it suitable for all sizes and configurations of electrically powered UAV[7].



Figure (I.6) : Commercial AEROPACK [7].

I.5 The energy management strategy

New energy sources such as hydrogen energy have been applied to the Unmanned Aerial Vehicle (UAV), which could be formed as the hybrid power sources due to the requirement of miniaturization, lightweight, and environmental protection issue for UAV.

Hybrid electrical propulsion technology has been used in UAV and it further enforces this trend for the evolution to the Hybrid-Powered System (HPS).

In order to realize long endurance flight mission and improve the energy efficiency of UAV, many researching works are focused on the Energy Management Strategy (EMS) of the HPS with digital simulation, ground demonstration platforms and a few flight tests for the UAV in recent years. energy management strategy, in which off-line or on-line control algorithms acted as the core part, could optimize dynamic electrical power distribution further and directly affect the efficiency and fuel economy of hybrid-powered system onboard.

In order to give the guideline for this emerging technology for UAV, this paper presents a review of the topic highlighting energy optimal management strategies of UAV.

The characteristics of typical new energy sources applied in UAV are summarized firstly, and then the classification and analysis of the architecture for hybrid power systems in UAV are presented. In the context of new energy sources and configuration of energy system, a comprehensive comparison and analysis for the state of art of EMS are presented, and the various levels of complexity and accuracy of EMS are considered in terms of real time, computational burden and optimization performance based on the optimal control and operational modes of UAV. Finally, the tendency and challenges of energy management strategy applied to the UAV have been forecasted.

I.6 The Model Of Fuel Cell Hybrid System

Hybrid fuel cell vehicle power system is a multi-power generation power system, which includes the motor, fuel cell system, batteries, DC / DC converters and other components.

According to a specific control strategy, the input power and output power of the fuel cell, batteries and the recovered energy can be optimally allocated through the control system so that we can get the best fuel efficiency and better performance.

Chapter I

Conclusion

UAVs technology occupies all fields and its use invades the aviation field due to its many advantages, and work to improve and develop it has become in place and among the most important developments that have been made in the field of energy, as it is advisable to use fuel cells due to their importance as they give a very high level of efficiency and safety compared to others, as a result. For its ability to convert chemical energy into electricity directly, its maintenance is very easy and simple, it lasts for a very long time, and most importantly, it does not emit any pollutants, which is considered a clean source of energy.

To improve performance, several energy management strategies for hybrid vehicles have been introduced

In the next chapitre is devoted to study modele dynamics of quadritor .

Chaptre II

- Modeling and simulation of
the UAV

II. 1 Introduction

objective of this chapter to studying the problem of managing electrical energy on board the vehicle, we will start by modeling the different sources of the electric vehicle considered.

The essential components are the energy sources used in electric vehicles, including the PEM type FC and the lithium-ion type battery. This chapter is devoted to the modeling and numerical simulation of these sources.

This modeling is a mandatory and useful step if we want to make the best use of these sources in the electric vehicle.

II.2 The first operational UAV

It was during the Second World War, in front of the important losses of the aviation observation of each of the antagonists, that the idea of developing observation devices unmanned (neither pilot nor observer), for operational applications, has emerged.

However, the sensitivity to interference of their guidance systems made their use difficult, or even impossible.

The arrival of computers in the 1960s then made it possible to consider autonomous, able to operate over a given area in order to collect valuable information. It was at this time that the first European drones appeared in France, such as the R20 developed by the Nord-Aviation company and derived from the CT20 target machine used as target for fighter jets or missiles. Intended for the surveillance of battlefields, this R20 reconnaissance drone, operational from 1966 to 1976, is equipped with a flight program internal, which makes it immune to interference [3].

Since that time, considerable progress in areas such as computerization, robotics, optronics, radar imagery or the transmission of The data has made it possible to extend the use of drones to increasingly diverse missions[4].

Moreover, the concept of "zero death" conflict, of American origin - in reality the wish of a strict limitation of human losses - can only increase the use of these devices[4].

Drones are aircraft capable of flying and performing a mission without a presence human on board. Of English origin, the word "drone", which means "drone", or "drone" is commonly used in French in

reference to the noise some of them make in flying, the term is used to designate air, land, surface or submarine vehicles, while the Anglosaxon classification distinguishes each type of device.

II.3 Classification of UAVs

II.3.1 Main categories (by size)

There is no single way to classify drones as they can be classified according to several criteria: range, range, altitude, mission, control system, etc.

However, for security reasons in national airspace, several countries have looked at the classification of these drones.

The drone family is classified by size as follows:

- ❖ mini and micro drones
- ❖ tactical UAVs, slow or fast, (fixed or rotary wing) called TUAV (Tactical Unmanned Air Vehicle)
 - combat UAVs, also calledUCAV (Unmanned Combat Air Vehicle)
- ❖ Strategic “high endurance” drones:
 - drones flying at medium altitude and long range called MALE (Medium Altitude Long Endurance)
 - drones flying at high altitude and long autonomy called HALE (High Altitude Long Endurance)

II.3.2 The mini and micro UAVs

The mini UAVs is perfect for getting started in learning to fly a real drone Small, light, easily transportable and practically unbreakable, the mini-drone is the must of must for training in real flight conditions! [4]

Micro-UAVs, whose dimensions are less than 15 cm, weighing about 50 grams, for a cruising speed of around 50 km / h, a range of about twenty minutes and a range of about ten kilometers.



Figure (II.1) The form of mini and micro UAVs

II.3.3 Tactical UAVs

With a range of up to more than one hundred kilometers, their weight can greatly exceed the ton.

They require a large logistical footprint and sometimes installations furnished. Their endurance can reach 8 hours and their payloads multi-functional.

The use of high performance drones, specifically designed for combat, is envisioned within true mixed combat systems, alongside combat aircraft piloted.

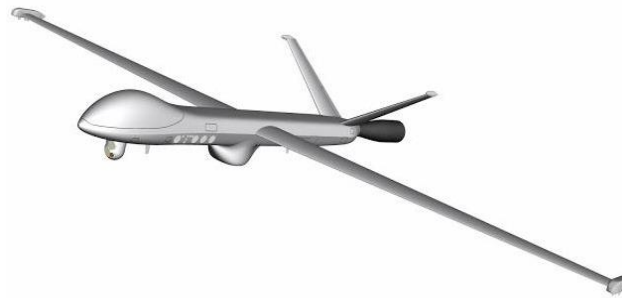


Figure (II.2) The form of fixed-wing tactical UAV

II.3.4 The strategic UAVs "high endurance"

➤ HALE UAV (High Altitude Long Endurance)

In this category, we reach the dimensions of a civil aircraft (Airbus A320 for example) for ranges of several thousand kilometers (10,000 km and more) traveled in flying well above common air traffic, both civilian and military (up to 20,000 m altitude). The engines are this time turbojets.



Figure (II.3) The form of HALE drones

II.4 PEM fuel cell model

Many works such as for example [10], [11] and [12] propose a static model describing the polarization curve of the PEM stack (Figure II.4) as the sum of four terms: the theoretical no-load voltage E_{Nernst} , the activation overvoltage V_{act} (or activation drop: region 1), the ohmic overvoltage V_{ohm} (or ohmic drop: region 2) and the concentration overvoltage V_{conc} (or concentration drop: region 3).

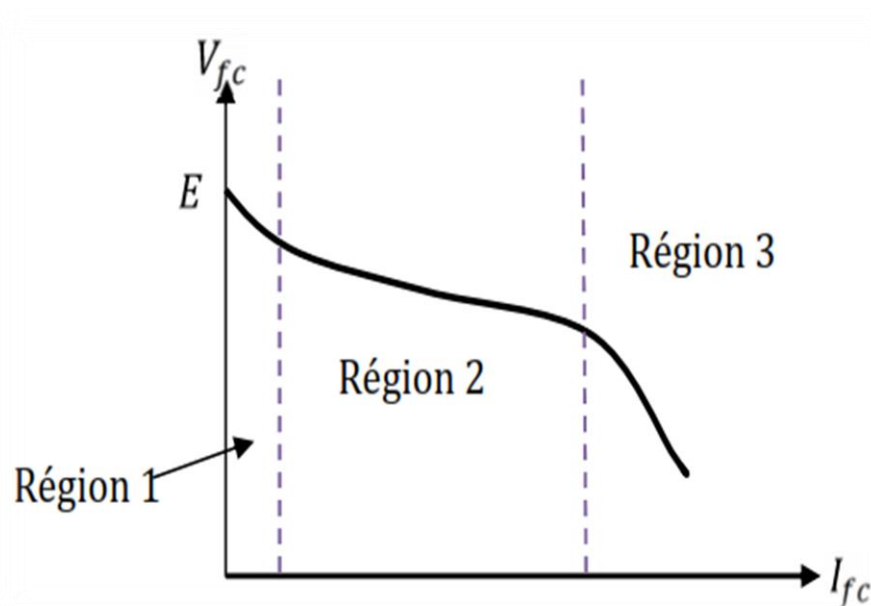


Figure (II.4): Static characteristic of a FC.

II.4.1 The no-load voltage of the fuel cell Nernst equation:

The fuel cell directly converts chemical energy into electrical energy. The chemical energy released by PàC is determined by the change in Gibbs free energy (Δg_f), which is the difference between the Gibbs free energy of products and the Gibbs free energy of reagents. Gibbs free energy is used to calculate the available energy needed for external work.

The variation of Gibbs free energy for the fuel cell is given by the formula below:

$$\Delta g_f = g_f \text{ des produits} - g_f \text{ des réactifs} = (g_f)_{H_2O} - (g_f)_{H_2} - (g_f)_{O_2} \quad (\text{II. 1})$$

The variation of Gibbs free energy depends on temperature and pressure [13]:

$$\Delta g_f = \Delta g_f^0 - RT_K \ln \left[\frac{P_{H_2} P_{O_2}^{\frac{1}{2}}}{P_{H_2O}} \right] \quad (\text{II. 2})$$

Where: Δg_f^0 is the Variation of Gibbs' free energy at standard pressure (1 bar) which depends on the Temperature T_K expressed in Kelvin.

P_{H_2} , P_{O_2} and P_{H_2O} : pressures of hydrogen, oxygen and water vapor.

R: Universal gas constant (8.3145 J / (kg K)).

Note that the value of Δg_f^0 is negative (-237.2 kJ / mol) because the energy is released by the reaction. In the absence of fuel cell losses, all of Gibbs' free energy would be converted into electrical energy. For each mole of hydrogen two electrons pass through the external electrical circuit and the electrical work performed is calculated as follows:

$$L(\text{travail électrique effectué}) = -2FE \quad (\text{joule}) \quad (\text{II. 3})$$

Or :

F: is the Faraday constant (F = 96485 coulombs) which represents the electric charge of one mole of electrons.

E: No-load voltage of the fuel cell.

This electrical work is equal to the variation of Gibbs free energy if the system is lossless:

$$\Delta g_f = -2FE \quad (\text{II.4})$$

The no-load voltage of the fuel cell can therefore be expressed by the following expression:

$$E_{\text{Nernst}} = \frac{-\Delta g_f}{2F} = \frac{-\Delta g_f^0}{2F} + \frac{RT_k}{2F} \ln \left[\frac{P_{H_2} P_{O_2}^{1/2}}{P_{H_2O}} \right] \quad (\text{II.5})$$

In practice, the operation of fuel cells is always accompanied by losses, part of the chemical energy being converted into heat.

The term $(-\Delta g_f^0)/(2F)$ varies depending on the operating point, it is equal to 1.229 V in the standard state (25 °C and 1 bar).

II.4.2 Activation losses

Losses of activation are due to the start of chemical reactions at the anode and cathode. Some of the available energy is used to break and reform chemical bonds at the electrodes. If these losses occur at both electrodes, the oxidation reaction of hydrogen at the anode is much faster than the reduction of oxygen at the cathode.

It follows that the losses of activation are mainly due to cathodic reactions. The relationship between activation losses and current density is given by the Tafel equation [14]:

$$V_{act} = -b * \log \left(\frac{i}{i_0} \right) \quad \text{avec : } b = \frac{R * T_k}{2 * \alpha * F} \quad (\text{II.6})$$

Or :

i: Current density delivered by the fuel cell,

i₀: Exchange current density equivalent to the flow of electrons in the electrolyte / open-circuit electrode interface. and b the slope of the Tafel line.

II.4.3 Ohmic losses

Ohmic losses are due to the resistance of the electrodes and bipolar plates to the flow of electrons and the electrolyte to the passage of protons. The corresponding voltage drop is written [14]:

$$V_{ohm} = -(i * R_{ohm}) \quad (\text{II.7})$$

Where R_{ohm} is the total resistance of the fuel cell.

II.4.4 Loss of concentrations

The consumption of gases impoverishes the gas mixtures and reduces the partial pressure of the gases. This pressure reduction depends on the current delivered and the characteristics of the gas circuits.

This voltage drop is expressed as a function of a limiting current i_L , for which all the fuel being used, its pressure would drop to zero, and a constant k called the transport or mass transfer constant:

$$V_{\text{conc}} = \alpha_1 * i^k * \ln\left(1 - \frac{i}{i_L}\right) \quad (\text{II. 8})$$

II.4.5 Voltage across FC

By combining all the voltage drops associated with all the losses in the previous sections, the operating voltage of the fuel cell can be written in the following form [14]:

$$\begin{cases} V_{OUT} = E_{\text{Nernst}} + V_{\text{act}} + V_{\text{ohm}} + V_{\text{conc}} \\ V_{OUT} = E_{\text{Nernst}} + \left[-b * \log\left(\frac{i}{i_0}\right)\right] + [-i * R_{\text{ohm}}] + \left[\alpha_1 * i^k * \ln\left(1 - \frac{i}{i_L}\right)\right] \end{cases} \quad (\text{II. 9})$$

Or :

V_{OUT} : is the shutter battery voltage (V),

E_{Nernst} : represents the no-load voltage of the fuel cell (Nernst potential),

V_{ohm} , V_{conc} and V_{act} represent ohmic, concentration and activation surges, respectively.

II.4.6 Simulation of the fuel cell voltage model

The calculation of the parameters of equation (II.9) requires knowledge of the partial pressures of hydrogen oxygen and the saturation pressure of water which is a function of the temperature expressed in ($^{\circ}$ C) are expressed in the following form :

$$\log P_{H_2O} = -2.1794 + 0.02953 * T_c - 9.1837 * 10^{-5} * T_c^2 + 1.4454 * 10^{-7} * T_c^3 \quad (\text{II.11})$$

Partial pressures of oxygen in the cathode and hydrogen in the anode as a function of the temperature expressed in (Kelvin):

$$\begin{cases} P_{H_2} = 0.5 * (P / \exp(1.653 * i / T_K^{1.334})) - P_{H_2O} \\ P_{H_2} = (P / \exp(4.192 * i / T_K^{1.334})) - P_{H_2O} \end{cases} \quad (\text{II. 12})$$

The parameters used in the expression are given by the following table [14]:

<u>Constant</u>	<u>Value</u>
$R_{ohm}(\Omega/cm^2)$	0.19
Alpha α	0.5
$i_0(A/cm^2)$	$10^{-6.912}$
k	1.1
Alpha α_1	0.085
$i_L(A)$	1.4

Table II.1: battery parameter

Figures I.5, I.6 and I.7 represent respectively the activation, ohmic and concentration overvoltages for pressures equal to 3bar and at constant temperature equal to (80 ° C) as a function of the current density for a single cell. And figures I.7, I.8 represent the voltage and the power of the FC.

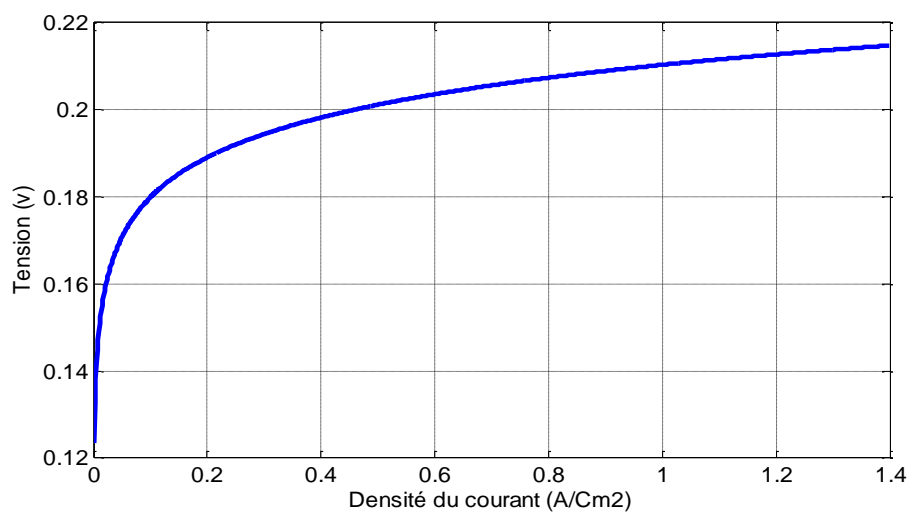


Figure (II.5): Activation overvoltage at temperature of 80 ° C and pressure of 3bar

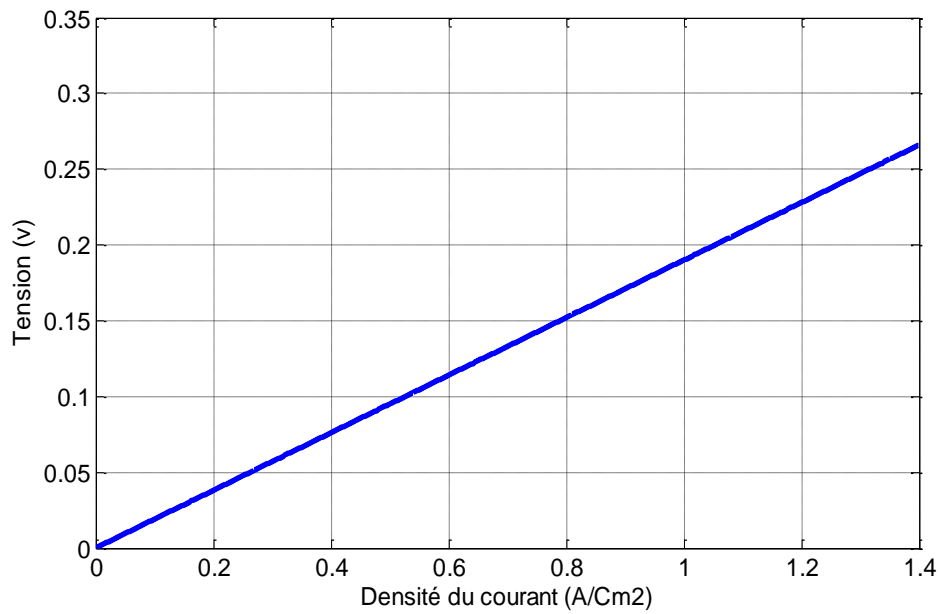


Figure (II.6): Ohmic overvoltage at temperature of 80 ° C and pressure of 3bar

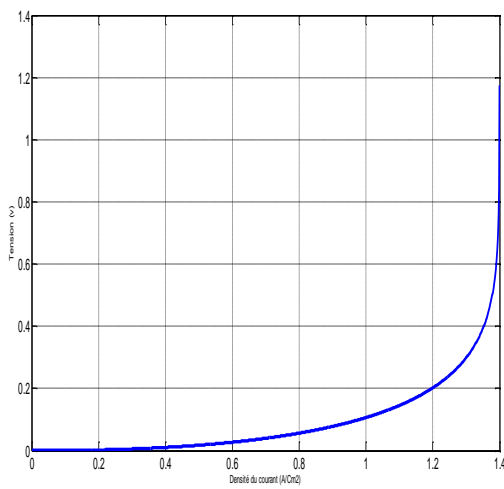


Figure (II.7) : Concentration overvoltage at temperature of 80 ° C and pressure of 3bar

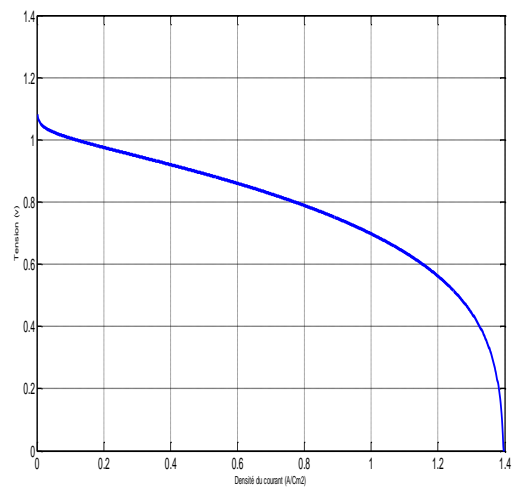


Figure (II.8) : Voltage of a fuel cell at a temperature of 80 ° C and a pressure of 3bar

The influence of pressure on the voltage level can be explained by the availability of gas molecules at the reaction sites. When the pressure is higher, there are more molecules in a given volume. We would therefore expect the performance of the battery to improve when the pressure rises. The increase in the pressure of the reagents should then make it possible to significantly improve the performance of the cell.

However, this model has the merit of being easy to characterize and gives sufficiently precise results for our needs. This model also has some flaws:

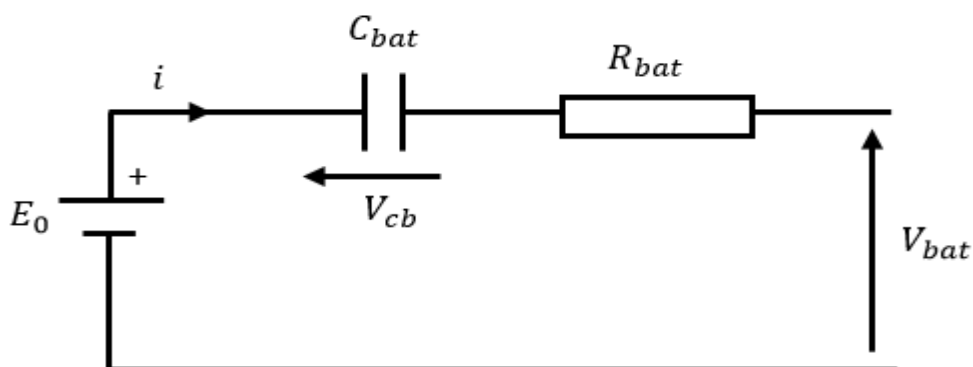
- The internal resistance of the model is a constant value and does not vary
- No effect of pressure variation.

II.5 Battery modeling

Certain models of accumulators make it possible to put in analytical form the phenomena related to the electrochemical reactions which occur during their use. The advantage is to be able to predict their behavior in different fields of application. The complexity of these electrochemical systems justifies the multiplicity of models and methods of identifying parameters to know, for example, the state of charge.

II.5.1 The simple electric battery model

This basic model allows, when the level of precision is not essential, to obtain basic results, but not very realistic, for example for the sizing of an energy system. It has been used by several authors to perform simulations when precision is not the priority. As shown in Figure.II.9, it consists of an ideal voltage source, equivalent to the open circuit voltage (E_0), and an equivalent series resistance (r_s). The output voltage is then expressed by the classical law of non-ideal voltage generators:



Figure(II.9): R-C model of the battery

So we have :

$$V_{bat} = E_0 - R_{bat} \cdot i - V_{C_{bat}} \quad (II.13)$$

The state of charge (SOC) of the battery is also defined by:

$$SOC = 1 - \frac{Q_d}{C_{bat}} \quad (II.14)$$

With: C_{bat} (Ah) the nominal capacity (Ah) of the battery and Q_d the quantity of charge missing compared to C_{bat}

This basic model is particularly simple to apply, but it does not take into account the variations in the internal impedance of the battery depending on the state of charge, the electrolyte concentration, the temperature or the number of cycles performed. This model therefore does not allow precise knowledge of the dynamic phenomena and the evolution of its behavior over time, but it may be sufficient for the first sizing of power electronic equipment.

In this work, we have modeled the model proposed by Tremblay [16]. It models the most popular rechargeable battery technologies. The parameters of the equivalent circuit can be changed to represent a particular type of battery based on its charge / discharge characteristic. When the battery current is negative, the battery will recharge according to the charge characteristic of the corresponding battery type.

Discharge model:

$$V_{bat} = E_0 - R_{bat} \cdot i - k \frac{Q}{Q-it} (it + i^*) + A \cdot \exp(-B \cdot it) \quad (II.15)$$

• Load model:

$$V_{bat} = E_0 - R_{bat} \cdot \text{Abs}(i) - k \frac{Q}{it-0.1Q} i^* - K \frac{Q}{Q-it} it + A \cdot \exp(-B \cdot it) \quad (II.16)$$

With:

V_{bat} : Battery voltage (V).

E_0 : The constant voltage of the battery (V).

k : The constant polarization (V / Ah) or (Ohm).

Q : The current battery charge (Ah).

$it = \int_0^t i \cdot dt$: Amplitude of the zone

A: exponential (V).

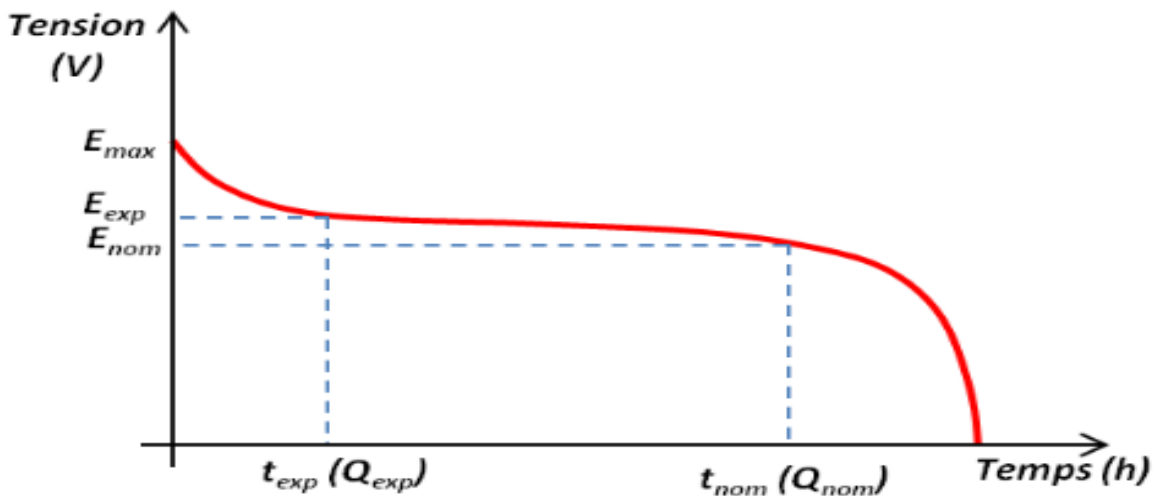
B: The battery capacity (Ah).

R_{bat}: Internal resistance (Ohm).

i: Battery current (A).

i^* : The filtered current (A).

II.5.2 Extraction of parameters [16]



Figure(II.10): Constant current discharge curve

The identification of the parameters of equation II.15 and therefore of the generic model, is based on the exploitation of the voltage drop curve of the battery (Figure. II.10) caused by a constant current discharge. This voltage variation is a characteristic supplied by the manufacturer for specific discharge regimes and temperature conditions. On this characteristic, the three points necessary to identify the parameters of the generic model are:

- $(E_{max}, 0)$ Battery fully charged,
- (E_{exp}, t_{exp}) ou (E_{exp}, Q_{exp}) End of the exponential variation zone.
- (E_{nom}, t_{nom}) ou (E_{nom}, Q_{nom}) End of the exponential variation zone.

The first two points are used to model the exponential part of the start of the characteristic $(A \cdot e^{-B \cdot it})$

with:

$$\begin{cases} A = E_{\max} - E_{\exp} \\ B = \frac{3}{C_{\exp}} \end{cases} \quad (\text{II.17})$$

A and B representing, respectively, the voltage drop and the inverse time constant in the exponential zone. C_{\exp} corresponds to the quantity of charges delivered by the battery at time t_{\exp} for the discharge current I_{dech} . It is calculated by:

$$C_{\exp} (\text{Ah}) = I_{\text{dech}} (A) \cdot t_{\exp} (\text{h}) \quad (\text{II.18})$$

From the voltage values E_{nom} and the quantity of charges C_{nom} we calculate the voltage polarization coefficient (K) as follows:

$$K = \frac{(E_{\max} - E_{\text{nom}} + (A \cdot e^{-B \cdot C_{\text{nom}}} - 1)) \cdot (C_{\text{bat}} - C_{\text{nom}})}{C_{\text{nom}}} \quad (\text{II.19})$$

C_{bat} Represents the nominal capacity supplied by the manufacturer and C_{nom} the nominal capacity estimated from the point $(E_{\text{nom}}, t_{\text{nom}})$ of the voltage curve (Figure. II.3). C_{nom} Is given by:

$$C_{\text{nom}} (\text{Ah}) = I_{\text{dech}} (A) \cdot t_{\text{nom}} (\text{h}) \quad (\text{II.20})$$

The last parameter to identify is the voltage constant E_0 . This is calculated from the voltage of the fully charged battery (E_{\max}) by equation (II.9). The latter takes into account the voltage variation due to the internal resistance and the discharge current (I_{dech}).

$$E_0 = E_{\max} + K + R_{\text{bat}} \cdot I_{\text{dech}} - A \quad (\text{II.21})$$

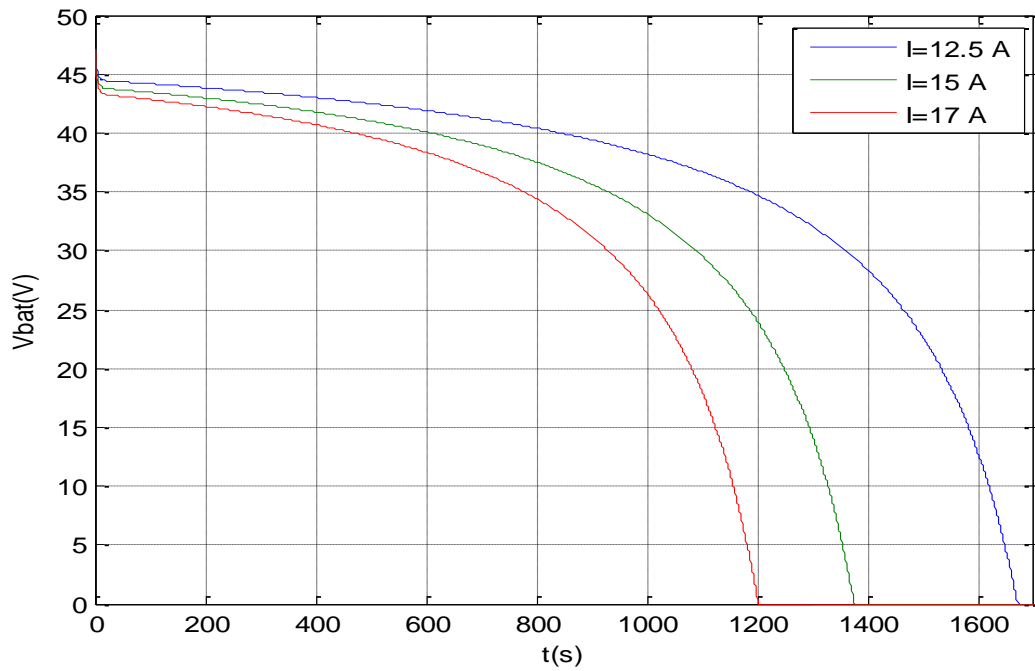
In the event that the value of the internal resistance R_{bat} is not provided by the manufacturer, it can be easily identified by a measurement.

The following table groups the parameters of the deferent type of battery tested, identified :

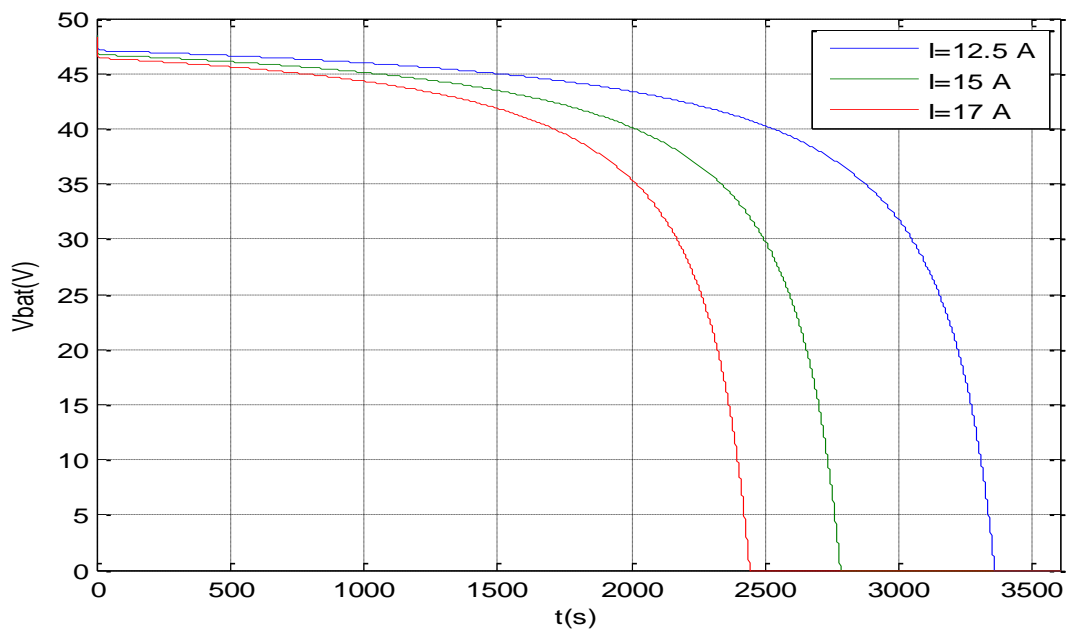
Type Paramètres	Lead-Acid 12V/7.2Ah	NiCd 1.2V/2.3Ah	Li-Ion 3.3V/2.3Ah	NiMH 1.2V/6.5Ah
$E_0(V)$	12.4659	1.2075	3.366	1.2816
$R_{bat}(\Omega)$	0.04	0.003	0.01	0.002
$K(\Omega \text{ or } V/(Ah))$	0.047	0.0037	0.0076	0.0014
$A(V)$	0.83	0.127	0.26422	0.111
$B(Ah)^{-1}$	125	4.98	26.5487	2.3077

Table II-2: battery parameter [16].

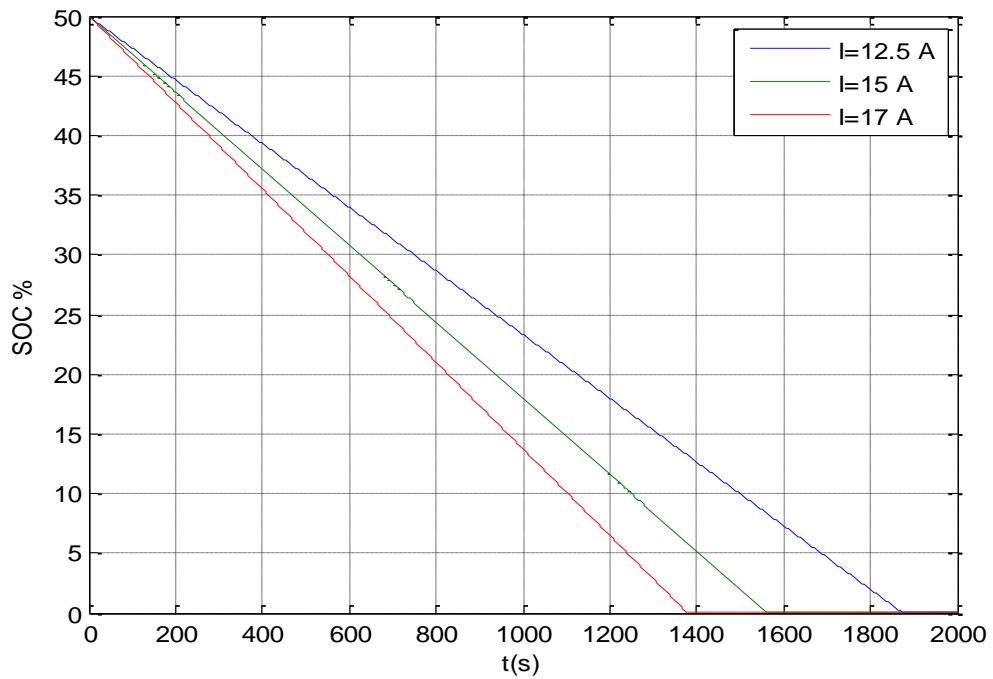
Figure (II.11) shows the simulation results of the evolution of the battery voltage for different discharge currents. We note that each time the discharge current increases the battery is discharged quickly and this comes back to the SOC characteristics of the lead acid battery. On the other hand, each time the charge current decreases, the battery charges rapidly as shown in Figure (II.12).



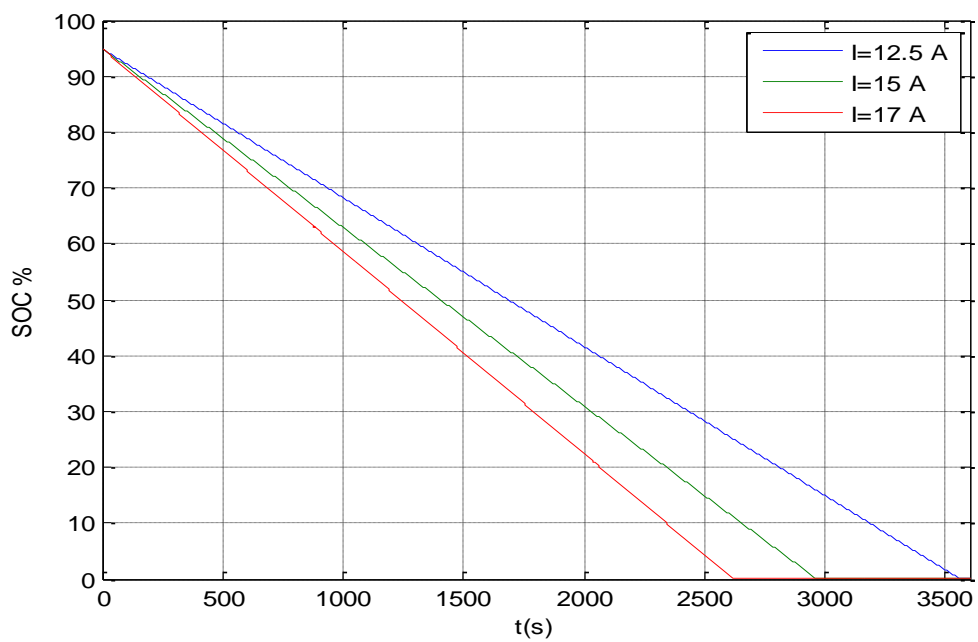
SOC=50%



SOC=95%

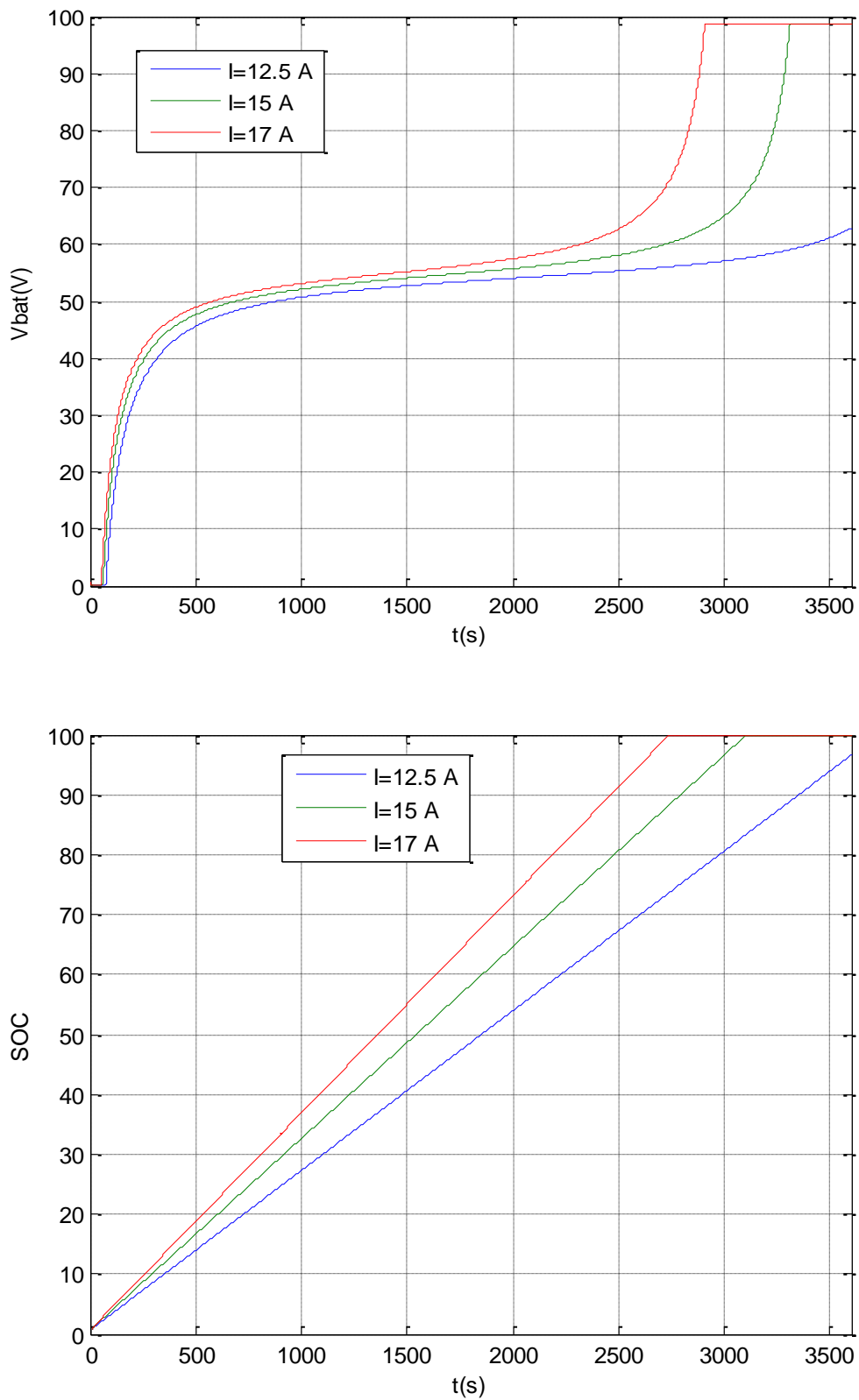


SOC=50%



SOC=95%

Fig(II.11) : Battery voltage and SOC for different discharge currents.



Fig(II.12): Battery voltage and SOC for different charging currents.

Conclusion

In this chapter, We started with the description of the general functioning of a uav and the different movements that it can perform during a flight, Conclusion

Before evaluating the behavior of multi-source uav, it is necessary to identify, study and model the different power sources that can constitute the electrical source for uav operation.

That is why in this chapter we have modeled the electrical power sources used in the realization of a hybrid source for a uav application.

These resources present themselves with different styles, behaviors, and characteristics.

These models are used in the next chapter to define the dimensions of the hybrid source, and to test the energy management strategies of uav fuel cell powered.

chaptre III

- Energy management strategy of the hybrid power source of Unmanned Aerial Vehicle

III. 1 introduction

This chapter is dedicated to the hybrid source power management strategies. Firstly, we present the frequency filtering needed to obtain the power needed by the drone. After that, we introduce the fuzzy logic in order to improve the power distribution between the battery and the fuel cell and make the battery well utilized, then we added an regulator PI in order to conserve battery charge and improve its range life time. Finally, the simulation results using variables illumination and load profiles will be presented.

III.2 Characteristic of different power sources

The power system of UAV is expected to have both high energy density and power density, namely plenty energy storage capacity and fast power response. Unfortunately, no any single new energy source can meet these two abilities without any compensation in current technical condition[20].

A comparison of power and energy density of different power sources is shown in figure (III.1)

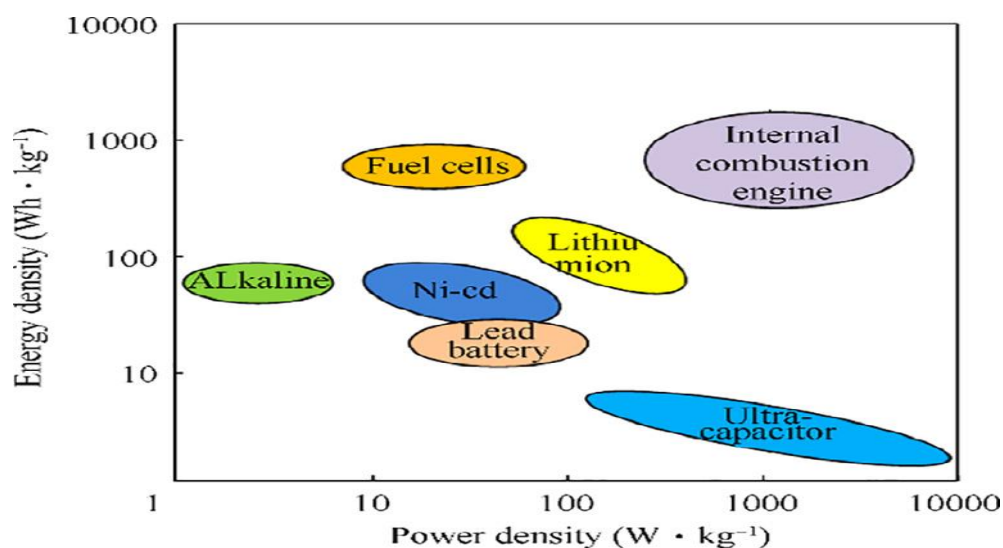


Figure (III.1) :comparison of power and energy density of fuel cell, batteries and UC.

For achieving similar overall performance to ICE, a hybridization of fuel cell, battery and UC is indispensable.

Figure (III.2) presents a typical UAV flight profile Where the P-load curve is the load power Note during the boot phase, the power level is about 400 watts at time 0 s

It can be seen that during take off and climb phase, the load power is 1200 watts at a time of 100 s to 130 s[20].

We also notice that in the down and down the load force is at a relatively low and stable level. During the landing phase at 400 seconds the rated power is 600 watts

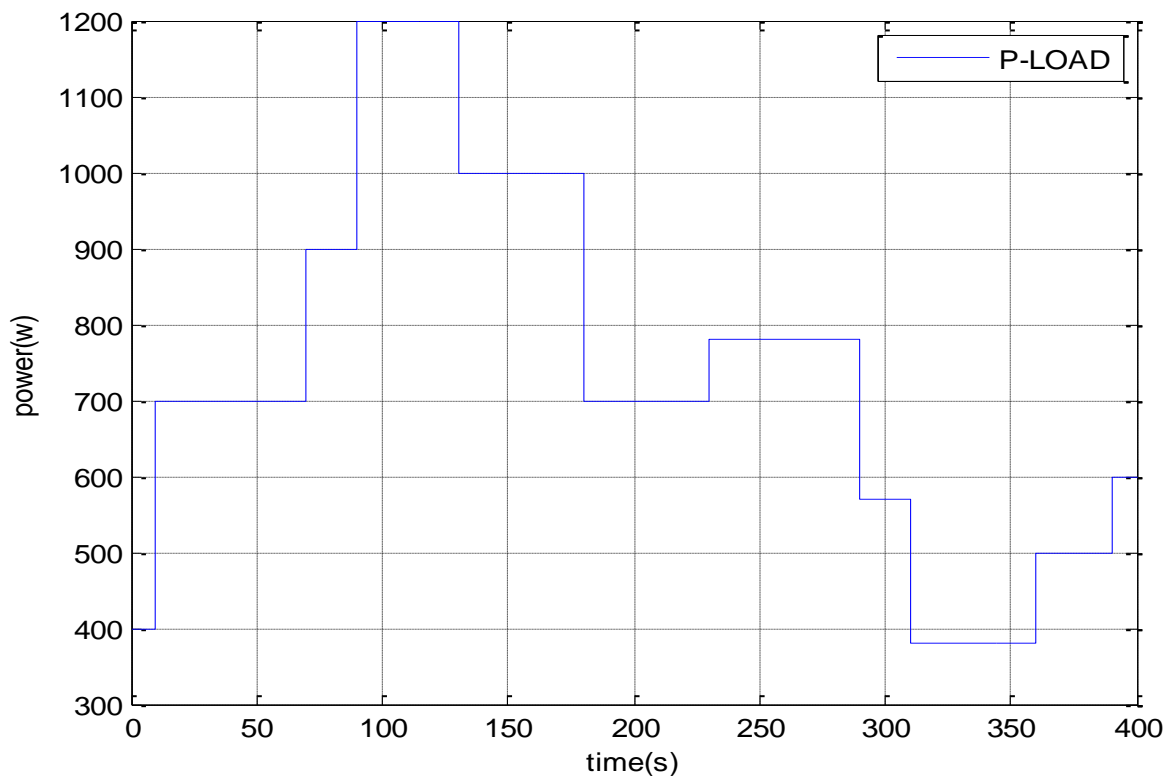


Figure (III.2) :power profile of UAV.

III.3 Energy management strategies EMS:

An energy management strategy is a key to developing electric power vehicles as it determines the life of an energy storage system.

In this part, we focus on energy management in a hybrid ESS, So our main goal is to test methods of energy management.

The study will be two energy management strategies (EMSs).

The main parameters:

Main parameters		Values
Flight profile	power requirement	0-1200w
PEMFC	voltage rang	48 V
	Maximum power	1000w
	Number of cells	48
	Numinal stack efficiency	50 %
battery	fully charged voltage	41.4 v
	Normal voltage	37 v
	Maximum current	12.5 Ah
	Of discharging/charging	20A / 2.4 A

Table(III.1): Main parameters[20].

III. 4 EMS for hybrid power system

EMS is a series of objective functions , The required load power is represented by P-LOAD P-BAT and P-FC correspond to output power of fuel cell, battery respectively. The subscripts such as ‘min’, ‘max’ and ‘scope’ are constrains of maximum value, minimum value and instantaneous rate of charge for corresponding variables.

Based on above-mentioned descriptions, for designing an optimal energy management strategy, a proper architecture should be determined firstly according to the power flow and standard requirements of UAV, and the optimization criteria need to be achieved by an objective function of algorithms[20].

The modeling and parameters of algorithm will be modified and regulated under repeated tests within the corresponding constrains until obtaining the optimal performance as expected. The detail flow chart for designing EMS is shown in Figure (III.3).

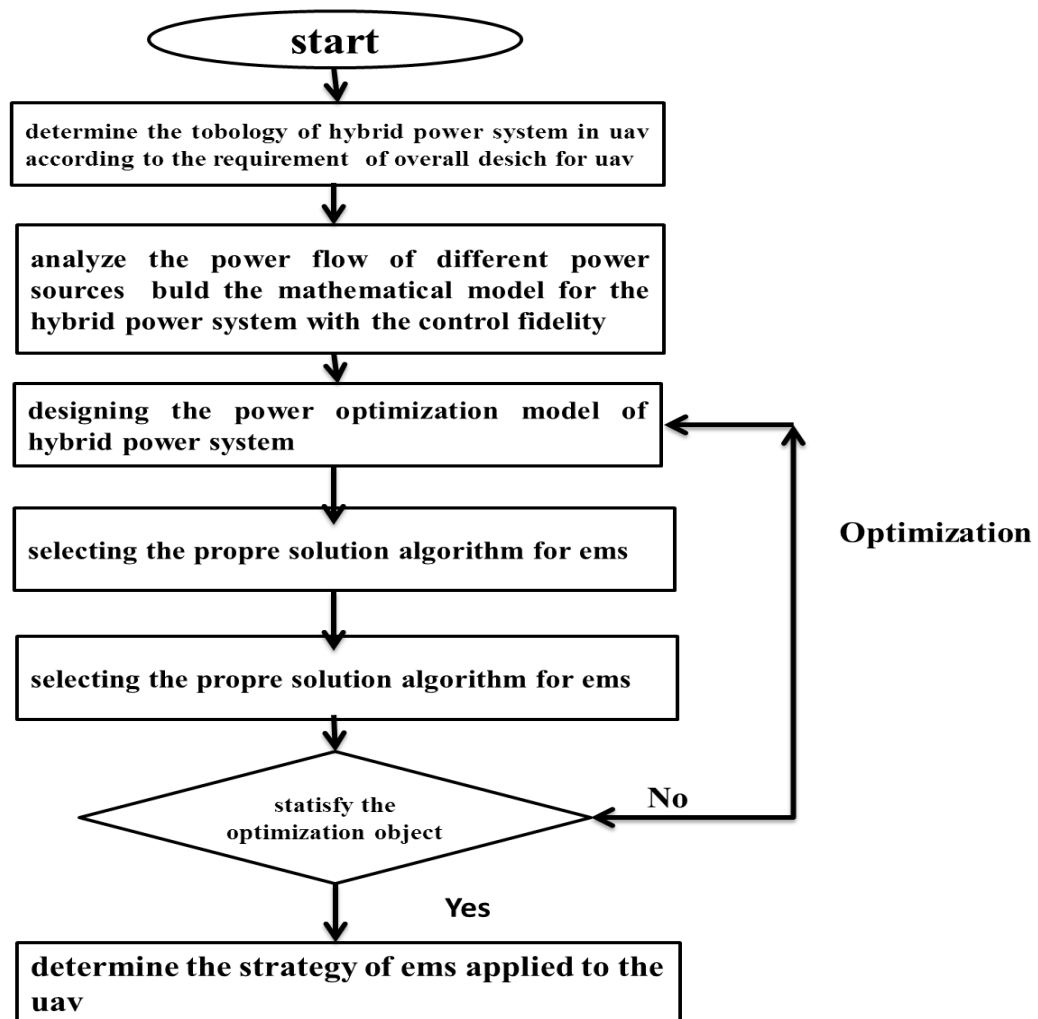


Figure (III.3) :organigram of designing the EMS.

III.4..1 advantage of the EMS:

- ✓ Improvement in fuel consumption.
- ✓ Improvement in efficiency.
- ✓ The length of the flight is further.
- ✓ Long life of power supplies.

III.4.2 Frequency energy management strategy :

The main objective of this strategy is to define the task of each energy storage component on the basis of frequency width, the principle of which is illustrated in the Figure (III.4) as the energy demanded by the uav is filtered out by a low pass filter[23].

The EMS has been detailed and the idea is to equally analyze total, load force, into two frequency components to which each component will be assigned the generator is fed low frequency that will be allocated to the fuel cell[23].

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The low frequency components are supplied by P-FC, and the high frequency components are supplied by the battery pack. Thus it is the value of the cutoff frequency that determines the mission of each source.

This value is directly related to the intrinsic properties of the storage component.

This strategy is to make the two sources complementary, taking into account the intrinsic characteristics of each source to ensure the overall mission uav.

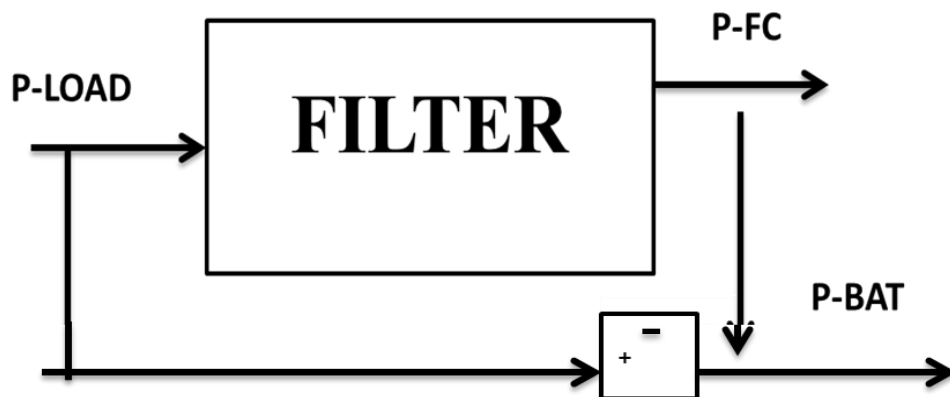
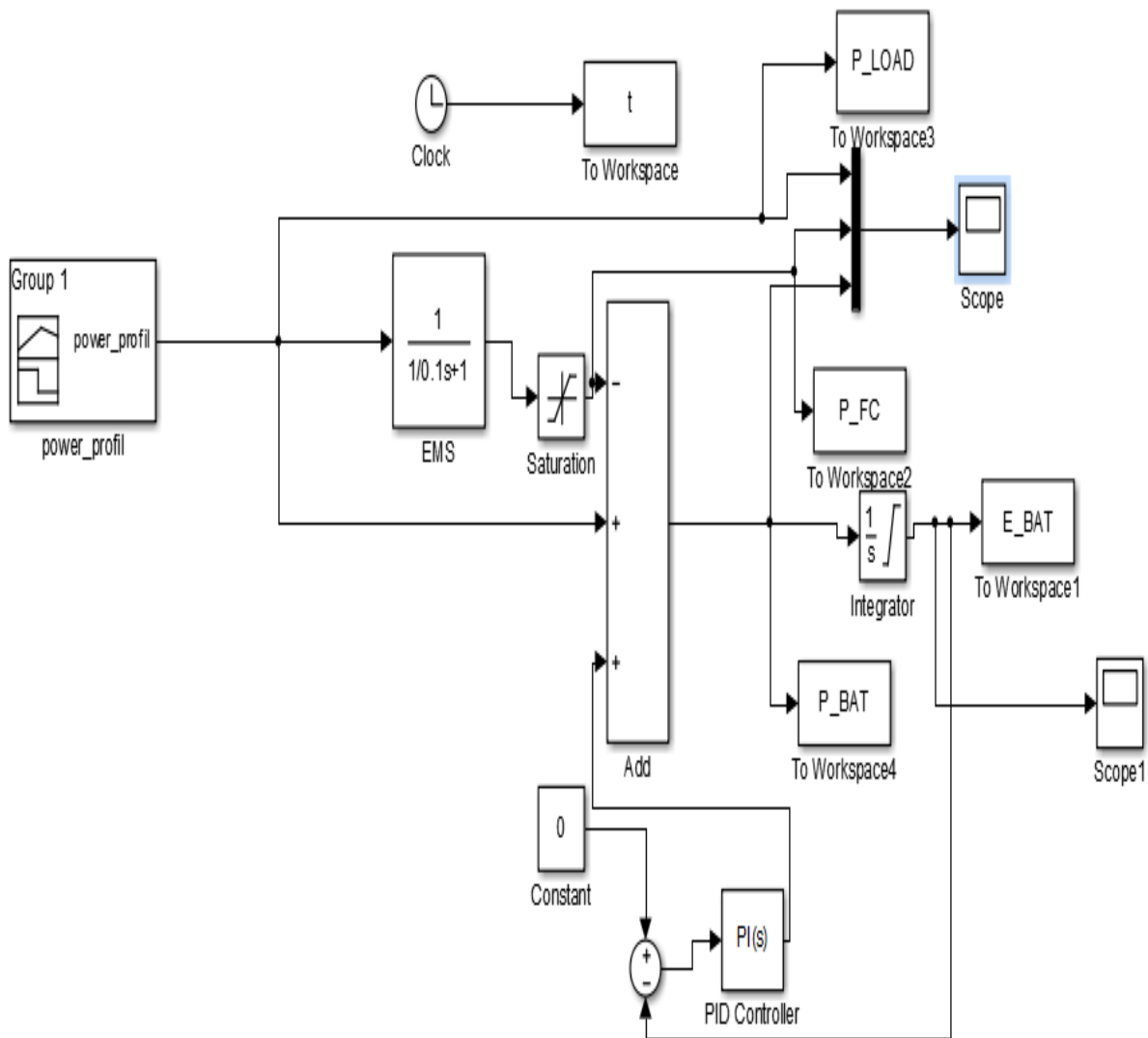


Figure (III.4) : Principle of the frequency energy management strategy

III.4.2.1 Simulation :

Figure (III.5) present the simulation scheme of the frequency separation energy management strategy where the power profil is introduced as an input to the strategy and fuel cell and battery power profiles as ouputs :



:

Figure (III.5) : schema simulation Frequency energy management strategy

Figure (III.6) represents the power profile where Pload represents the load power and P-fc and P-bat are the output power of the fuel cell and the battery, respectively.

During the takeoff phase the power level is around 400 watts, and the power is 600 watts during the landing phase.

It can be seen that during takeoff and flight phase, the load force is the largest and exceeds the maximum power of both P-FC and P-BAT.

Also note that the P-FC energy demand occurs in a downward phase with high volatility which leads to serious energy loss

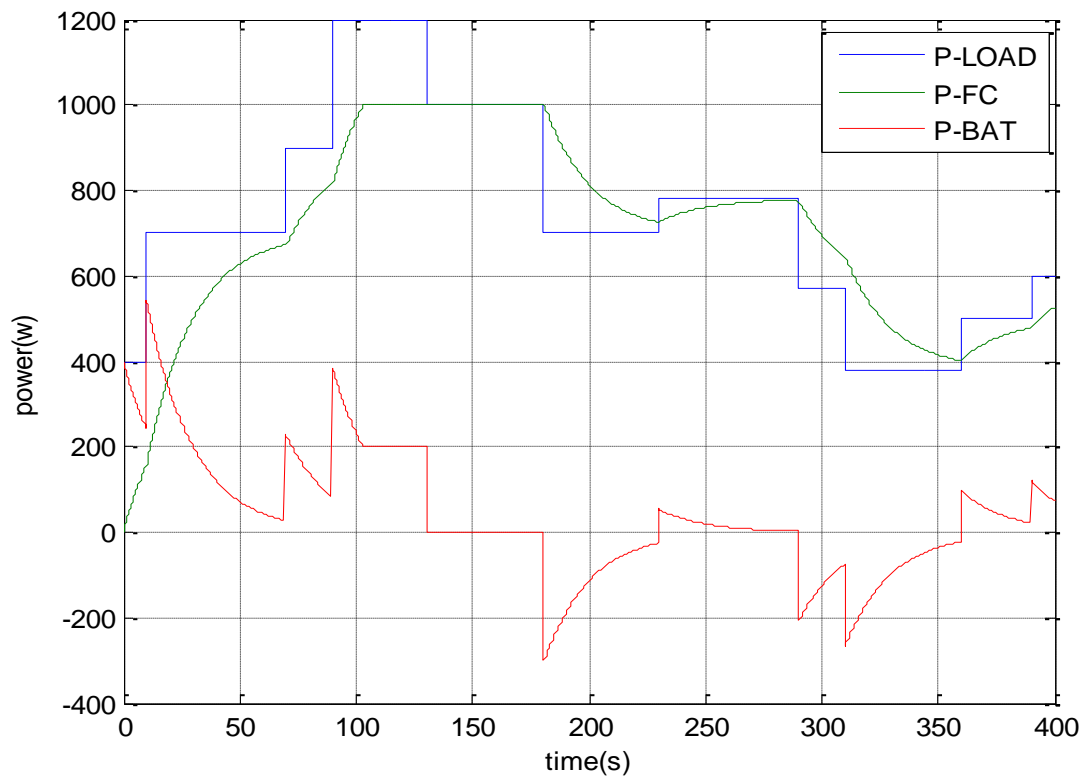


Figure (III.6) : Power response

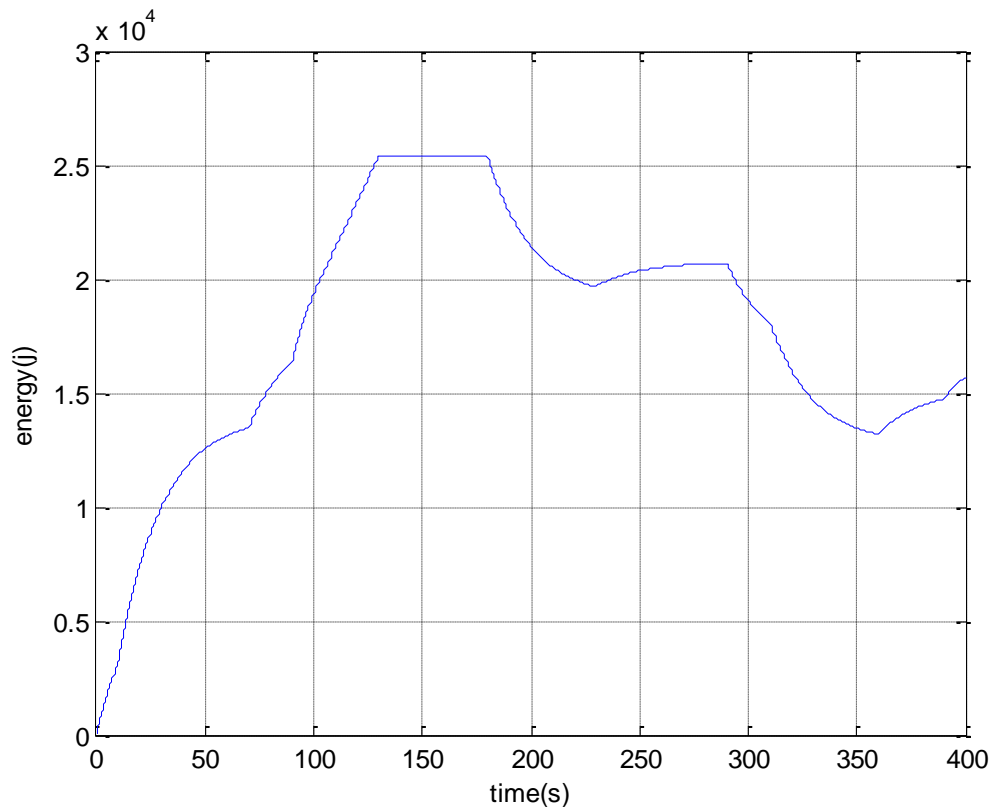


Figure (III.7) : results of energy management strategies

Figure (III.7) results of the frequency strategy, it is clear that this technique correctly prevents the P-FC system from responding to large power slopes and forces each source to respect its own characteristics.

It can be seen that the battery reacts instantly to supply transient power peaks which cannot be provided by the P-FC.

III.4.3 Intelligent-based energy management strategy with fuzzy logic controller (FLC)

The intelligent algorithm, which is constructed by some imitative behaviors can achieve automatic control to a specific object.

These algorithms have made a great development and successful application in hybrid power system. Fuzzy Logic controller (FLC) is one of the major[21].

III. 4.3.1 Defenition

Fuzzy Logic is an approach to variable processing that allows for multiple values to be processed through the same variable. Fuzzy logic attempts to solve problems with an open,

imprecise spectrum of data that makes it possible to obtain an array of accurate conclusions[30].

Fuzzy logic is designed to solve problems by considering all available information and making the best possible decision given the input[22].

III. 4.3.2 Principle of fuzzy logic

Fuzzy logic is a theory introduced by L. A. ZADEH in 1965 , Fuzzy logic gives a very appreciable flexibility to the reasoning that uses it, which makes it possible to take into account imprecisions and uncertainties.

This technique is suitable for solving problems where uncertainties mar the knowledge available on the system.

This technique should be used when the rigorous modeling of the system is difficult or when it is very complex to understand and to order [24]. The internal configuration of a decision-based system of fuzzy logic is given by Figure (III.8) .

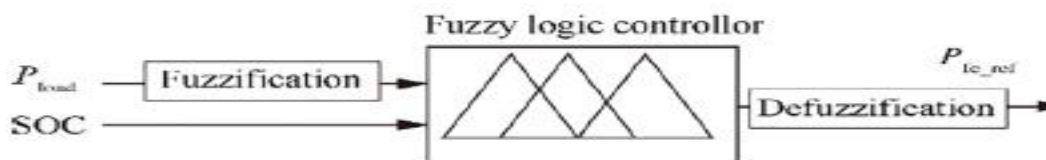


Figure (III.8) : Synoptic overview of a fuzzy system

The fuzzy system input variables are broken down into several sets what are the membership functions represented in several forms, namely triangular, trapezoidal or other shapes.

III. 4.3.3 Fuzzification

Is the first processing step in the structure of a controller fuzzy type. It consists of weighting the membership functions of the inputs to the various sub-assemblies. This method allows the passage of physical quantities into linguistic variables that can be processed by inferences[30].

The fuzzy inference system is based on expertise applied to the system to the definition of linguistic terms corresponding to each variable on the one hand, and on the learning algorithms for the generation of rules on the other hand. It allows to move from degrees of membership of input quantities to degrees of membership fuzzy subsets of the output variables[26].

III. 4.3.4 Defuzzification

Is the last step that is used to produce a quantifiable result in fuzzy logic, taking into account fuzzy sets and degrees of membership correspondents. This is the reverse transformation of the fuzzification module.

This step therefore consists in combining the coefficients with the output subsets, to convert them into one or more control signals[30] .

It is clear that fuzzy logic, by its capacity to reproduce human reasoning, seems particularly suited to the distribution of power in a source hybrid storage. It has indeed the robustness necessary to take naturally take into account system variations .

The application of this approach in the field of energy management of system hybrids is a subject of great interest to academic and industrial researchers. Several research studies have tested this approach. In most of the work, the main objective is the satisfaction of the propulsive power as well as improved power distribution between sources. They use the propulsive power and energy state of the secondary source input variables and the reference power as the output variable[28].

In our system the power distribution energy is provided by a fuzzy rule-based controller like those used in.

The reference power of the system depends on the state of battery charge and instantaneous propulsion power.

The two input parameters will be fuzzified using membership functions. The concept of membership function will allow us to define systems fuzzy in natural language, the membership function making the link between the quantities parameters of our fuzzy system[27].

and the linguistic variables that we will to define .

III. 4.3.5 Choice of membership functions

The universe of discourse of each of the fuzzy controller variables is divided into several classes or subsets. Each of these subsets describes a state of the designated variable[23].

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A simple FL scheme and trapezoidal membership function are shown in Figure (III.9) . the SOC and load power are utilized as two inputs, and reference power of PEMFC is to be the single output.

The membership function about load power consists of 4 fuzzy linguistic variables: Zero (ZE), Positive Small (PS), Positive Medium (PM), Positove Big (PB) the function about on SOC includes variables: Low (L), Middle (M), High (H).

In order to improve the stability of output power of fuel cell, 4 variables are set in the corresponding membership function: OFF, Minium(Min),Medium (MED), Maxium (Max).

The choice of these membership functions is closely related to the set of inference rules characterizing the decision system by linking the system inputs to the single output.

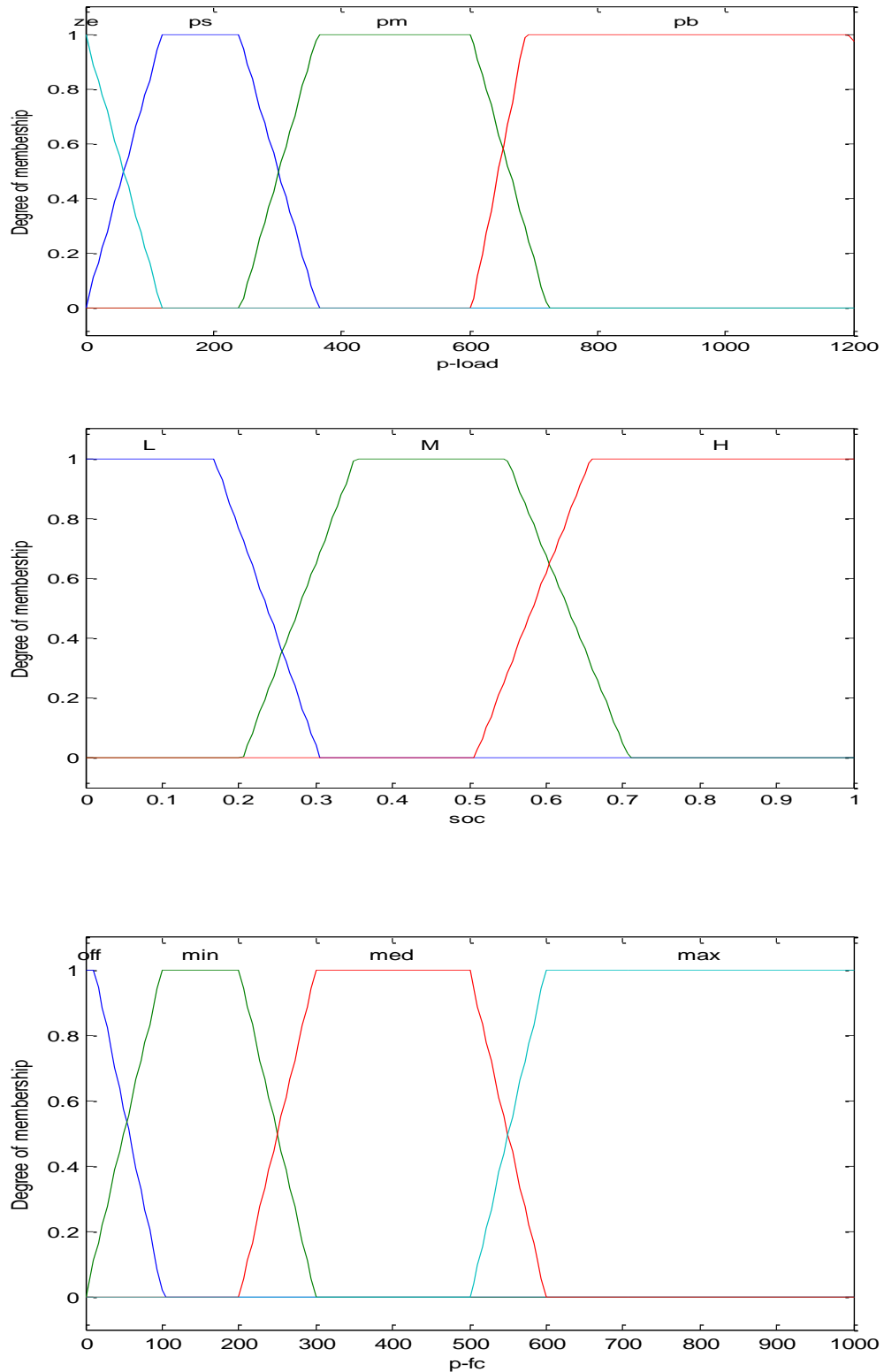


Figure (III.9) : Discourse universe and membership functions of variables

III. 4.3.6 Fuzzy inference mechanism

Fuzzy inference or decision-making logic is the heart of the fuzzy controller who owns the ability to simulate human decisions and infer (infer) fuzzy control actions from using fuzzy implication and fuzzy logic inference rules.

She uses variables fuzzy shapes transformed by fuzzification and inference rules to create and determine the fuzzy output variables, based on fuzzy operations applied to functions of belonging [23].

As mentioned, there are several possibilities to realize fuzzy operators which apply to membership functions.

We introduce the notion of mechanism or method of inference, which depends on the relationships used to realize the different operators in an inference, thus allowing a treatment digital of the latter.

For fuzzy logic tuning, one of the following three methods is generally used:

- Max - Min inference method (Mamdani method).
- Max - Product inference method (Larsen method).
- Sum - Product inference method.

III. 4.3.7 Choice of inference rules

The design of the control system (RFL) is based on an approach similar to the one used in [23], where trapezoidal membership functions are used. The fuzzy rules are derived from the analysis of several operating states based on the charging power and the state of charge of the battery (see Table (III.2)).

The approach Mamdani fuzzy inference is used with the centroid method for defuzzification.

IF <i>P</i> -Load ze	AND	<i>SOC L</i>	SO	<i>P</i> -FC off
IF <i>P</i> -Load ps	AND	<i>SOC L</i>	SO	<i>P</i> -FC min
IF <i>P</i> -Load pm	AND	<i>SOC L</i>	SO	<i>P</i> -FC med
IF <i>P</i> -Load pb	AND	<i>SOC L</i>	SO	<i>P</i> -FC max
IF <i>P</i> -Load ze	AND	<i>SOC M</i>	SO	<i>P</i> -FC off
IF <i>P</i> -Load ps	AND	<i>SOC M</i>	SO	<i>P</i> -FC min
IF <i>P</i> -Load pm	AND	<i>SOC M</i>	SO	<i>P</i> -FC med
IF <i>P</i> -Load pb	AND	<i>SOC M</i>	SO	<i>P</i> -FC med
IF <i>P</i> -Load ze	AND	<i>SOC H</i>	SO	<i>P</i> -FC off
IF <i>P</i> -Load ps	AND	<i>SOC H</i>	SO	<i>P</i> -FC off
IF <i>P</i> -Load pm	AND	<i>SOC H</i>	SO	<i>P</i> -FC min
IF <i>P</i> -Load pb	AND	<i>SOC H</i>	SO	<i>P</i> -FC med

Table (III.2) :- Fuzzy Controller Inference Rules

III. 4.2.8 matlab simulation :

Figure (III.10) present simulation fuzzy logic controller (FLC) energy management.

This strategy is based on changing the power limits of the P-FC system according to the SOC batteries charge condition. Thus, it improves the life of the storage system

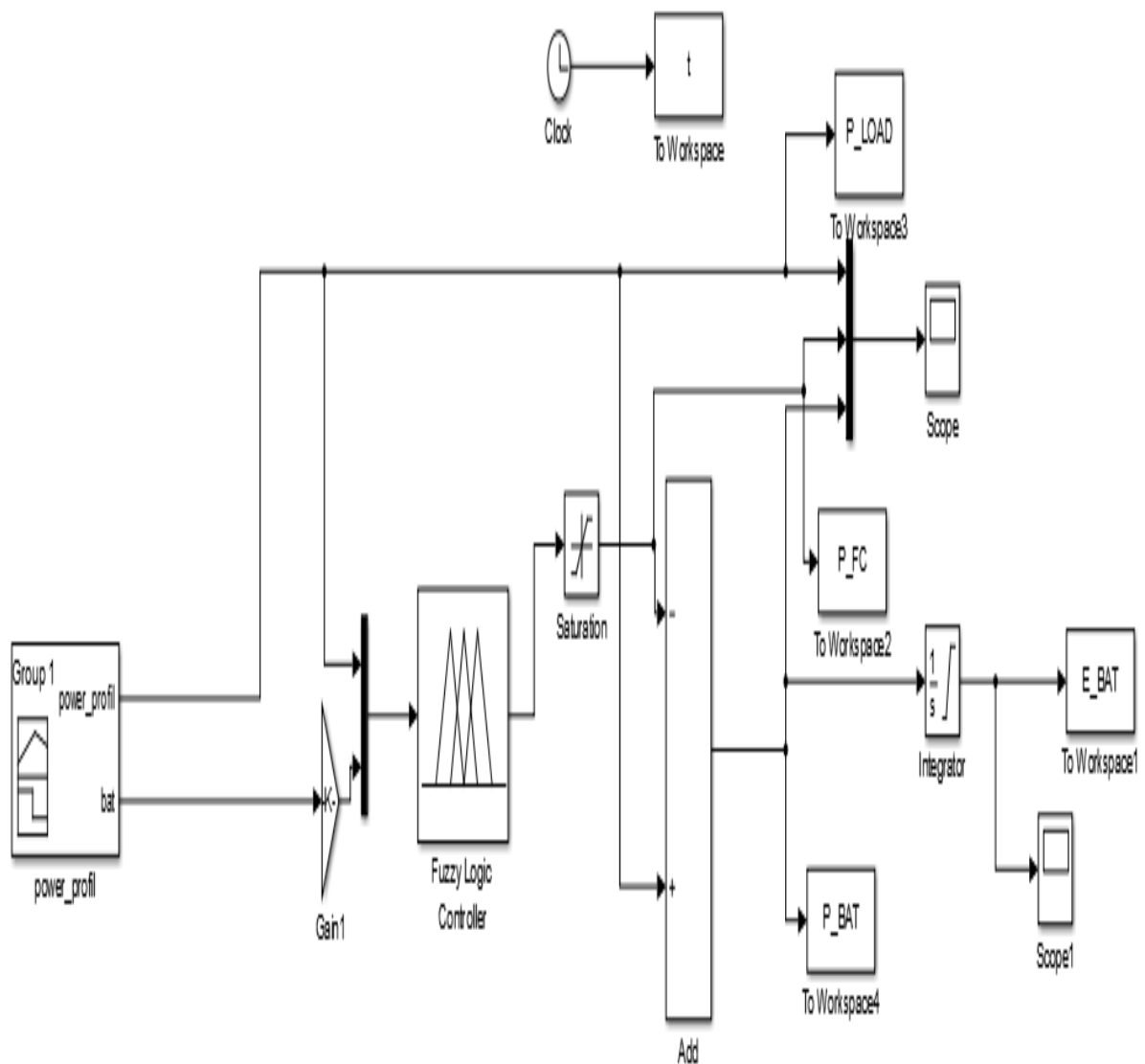


Figure (III.10) : simulation scheme fuzzy logic controller (FLC)

Figure (III.11) represents the power profile where Pload represents the load power and P-fc and P-bat are the output power of the fuel cell and the battery, respectively.

during takeoff and flight phase, the load force is the largest and exceeds the maximum power of both P-FC and P-BAT.

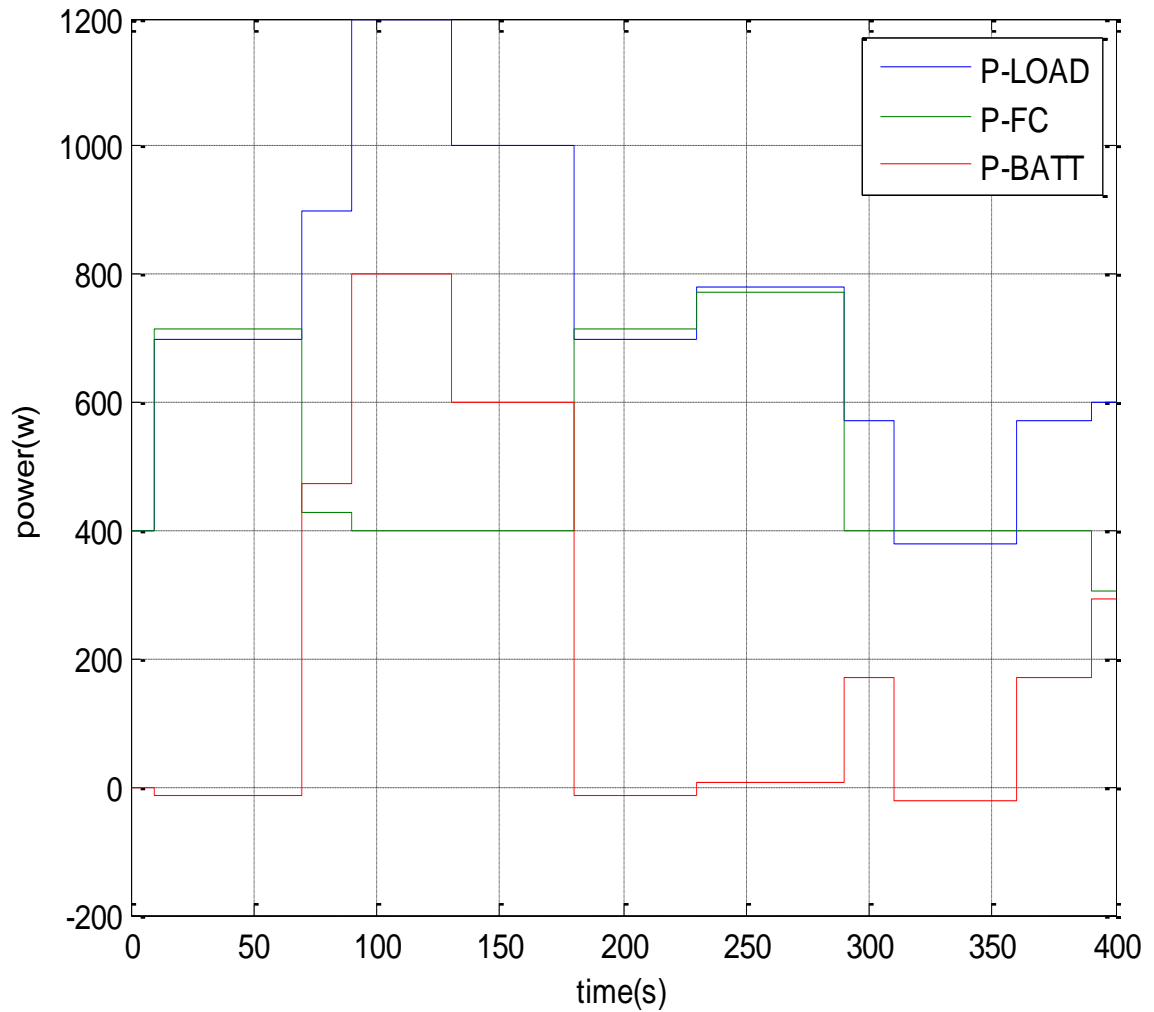


Figure (III.11) : Power response

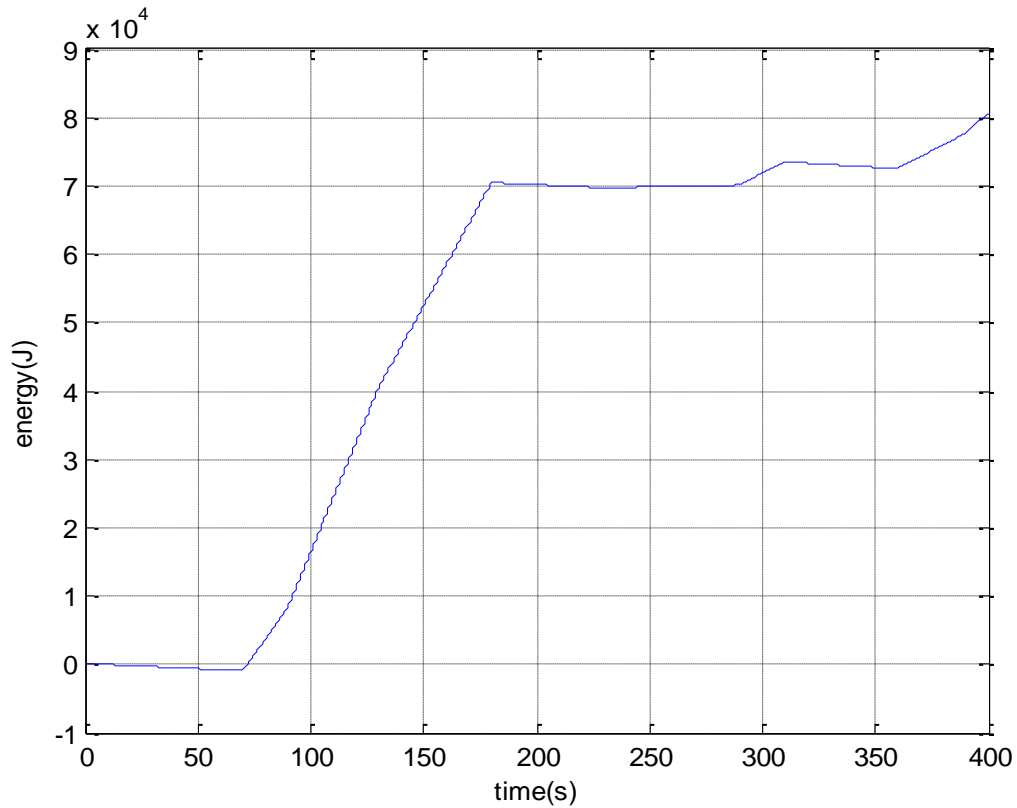


Figure (III.12) : Simulation results of energy management strategies

Figure (III.12) represent result of simulation on (RFL) strategy, the battery reacts immediately to power transient phases that cannot be provided by the P-FC system where the robustness of the proposed approach is confirmed. The P-FC system is well protected using this strategy where the characteristics are respected when designing the fuzzy controller. Also, the battery power state returns to its initial value and the battery does not participate .

When evaluating the results, we note that the RFL strategy provides less fuel cell energy than the frequency strategy ,So strategy (RFL) is the ideal solution in energy management.

Conclusion :

This chapter describes the power management of the battery / FC hybrid system under various conditions.

Frequency filtering strategy has been detailed and tested as it delivers a good performance.

Fuzzy logic was confirmed using variables and a battery load profile. It is linked by a PI regulator in order to maintain a battery charge.

Finally, the results obtained confirm the ability to control power distribution and obtain good performance.

General conclusion

General conclusion

Fuel cell systems, currently in the early stages of development, are an entirely different approach to producing electricity from traditional prime mover technologies. Fuel cells are similar to batteries in that both produce direct current through an electrochemical process without the direct combustion of the fuel source.

Fuel cells provide the ability to generate clean, quiet and efficient energy as is the case with most new technologies. In this study we gave comprehensive information about unmanned aerial vehicles, the definition of fuel cells, how they work, their applications and their advantages.

In this study, we proposed a hybrid electrical system consisting of a fuel cell (FC) and battery for an unmanned aerial vehicle (UAV) propulsion application. Based on the thrust requirements of the UAVs during takeoff, climbing and endurance, the hybrid power plant specifications were defined to respond to any thrust power demand.

We introduced the power management system to control the power flow between the fuel cell FC and the battery with a frequency strategy, then replaced it with fuzzy logic (FLC) and linked it with a classic PI controller in order to optimally control the power flow between the fuel cell and the battery and get the optimal result.

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