The 2015 World Congress on
Aeronautics, Nano, Bio, Robotics, and Energy (ANBRE15)
Incheon, Korea, August 25-28, 2015

Hybridization of a gas turbine with a battery for an APU function

*Mickael Faucher[1), Christophe Turpin[2), Fabien Lacressonnière[3),
Stéphane Vaillant[4), Jean-François Rideau[5), Guillaume Fontès[6)
and Stephan Astier[7)

[1), 2), 3), 6), 7)] *Université de Toulouse, INPT, UPS, LAPLACE (Laboratoire Plasma et Conversion d'Energie), ENSEEIHT, 2 rue Charles Camichel, BP 7122, F-31071 Toulouse cedex 7, France*
[1), 2), 3), 6), 7)] *CNRS, LAPLACE, F-31071 Toulouse, France*
[1), 4), 5)] *SAFRAN Microturbo, 8, chemin du pont de Rupé, BP 62089, 31019 Toulouse Cedex, France*
[1)] *Mickael.Faucher@microturbo.fr*

ABSTRACT

In an aircraft, the APU function (Auxiliary Power Unit) is essential to provide the electrical energy when the aircraft is parked (ground operations). In flight, the APU operates only in emergency mode (in the case of total power loss during engines failure) before the RAT (Ram Air Turbine) deployment. Today, the APU is based on the gas turbine powered by fuel. In order to limit the impact on the environment (CO2 emissions, noises...) and the operating cost of the APU function, we have studied the electrical hybridization of a gas turbine with a battery. This study presents the model of the gas turbine and the battery and the hybridization modelling network in order to evaluate several energy management strategies.

INTRODUCTION

To limit the impact of air traffic on environment, aircraft industry has to reduce fuel consumption and CO2 emissions. The “more electric aircraft” can help reaching these environmental and technological challenges. This electrification leads to develop novel topologies and energy management strategies. Thus, a hybridization of several electrical energy sources potentially optimizes, on the one hand, the utilization of each source and on the other hand, reduces the overall mass of the system. The accurate knowledge of each source is important for the dimensioning of this kind of embedded network. This paper presents the hybridization of a gas turbine with a battery.

First of all, the models of the gas turbine and the battery are presented. A comparison of simulation results and experimental tests allows validating the models. Afterwards, their hybridization is studied.

THE GAS TURBINE MODEL

The hydrocarbon combustion in a thermodynamic gas turbine produces mechanical energy. This energy (kinetic energy) is transformed in electrical energy with a generator.

A gas turbine is essentially composed of three major components: the compressor, the combustion chamber, and the power turbine. In the compressor section, the ambient air is compressed, the combustion chamber allows increasing the temperature and the power turbine generates the mechanical power shared between the compressor and the generator.

Given the complexity of a gas turbine system, a model based on the thermodynamic equations is very difficult to obtain. Thus, a model has been developed with mappings, obtained experimentally for each element.

A dynamic model of a gas turbine has been implemented in Matlab/simulink. The computing language of Matlab is well adapted for the mapping reading. The influence of temperature and altitude has been taken into account in the model. Moreover, the model has been developed to be flexible according to several load profiles.
In order to have a representative system, the parameters of the model have been calibrated with static operating points at different altitudes and different temperatures obtained by a static model with utilization of mappings. The comparison between the simulation results and the gas turbine experimental tests allows validating the model accuracy and, if necessary, adjusting the parameters of the model. Figure 1 presents, for a load profile, the rotation speed of the real gas turbine and the one obtained with the model.

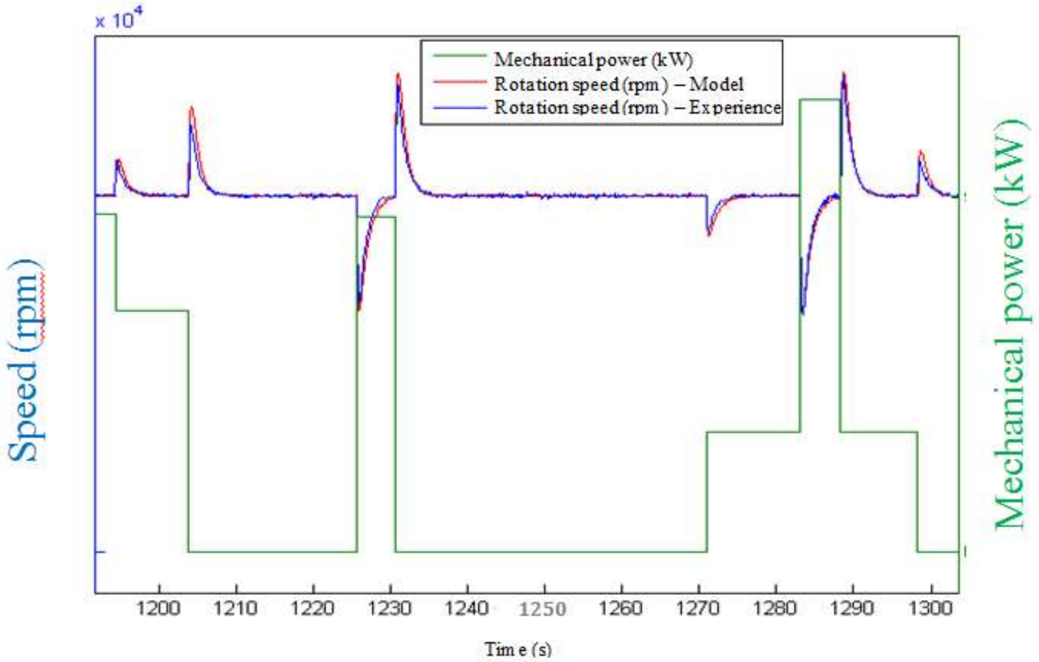

Fig.1: Gas turbine rotation speed.

The modelling of the gas turbine has allowed studying its dynamic behaviour. The knowledge of the dynamic performances permits to determine the best source which could be used, with the gas turbine, in order to develop the embedded hybridization network.

The simulation results have shown that the inertia of the gas turbine is similar to energy storage with a high dynamic performance like as ultracapacitors. Hence, the hybridization of a gas turbine with ultracapacitors is not justified in our case. However, according to the mission profile, an electrochemical storage system with a high energy density, like a battery, could potentially improve the dimensioning of the overall system.

THE BATTERY MODEL

A battery is composed of several electrochemical cells able to store electrical energy in the form of chemical energy and conversely. The oxidation/reduction processes that take place at the electrodes allow this energy transformation. However, the reaction kinetics in the electrochemical cell reduces the power density in opposite of an ultracapacitor. Nevertheless, the battery has a higher energy density. A lot of batteries modelling works exist as [1]-[3]. The battery model introduced in this paper is based on the previous works carried out in LAPLACE laboratory [4]. Figure 2 shows the dynamic model of an electrochemical accumulator. The voltage source E^0 is the standard cell potential and the C_{stock} capacitor models the main energy storage. The voltage at the terminals of C_{stock}, named E_{stock}, depends on the State Of Charge (SOC). The irreversible losses (ohmic phenomena, activation phenomena and diffusion phenomena) are modelled by 3 resistors. The activation and diffusion resistors depend on the SOC. The C_{dc} capacitor models the double layer capacitors at the electrode-electrolyte interfaces (the electrochemical double layer is a dynamic phenomenon combined to the activation phenomenon). Slow diffusion dynamics are modelled with a capacitor named C_{diff} (relaxation phenomena).

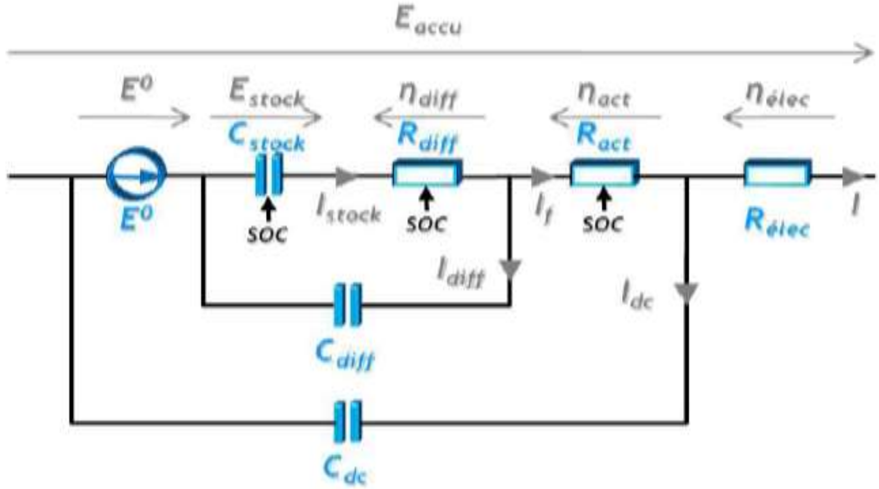

Fig. 2: Dynamic model of an electrochemical accumulator (one cell).

The OCV (Open Circuit Voltage) is determined by adding E^0 and E_{stock}. The standard cell potential E^0 depends on the active material of the electrodes and is given by the Eq.(1) and E_{stock} is calculated by the Nernst Eq.(2):

$$E0 = -\frac{\Delta H0 - T\Delta S0}{nF} \quad (1)$$

$$E_{stock} = \frac{RT}{nF} l\, n \frac{(Q_{tot} - Q)^a}{(Q + Qel)^b} \quad (2)$$

In these equations, Q_{tot} (Ah) is the total capacity of the cell, Q (Ah) is the charge consumed, Qel (Ah) depends on the initial concentration of lithium ions in the active materials of the cell, R (J/mol/K) is the molar constant for an ideal gas, F (C/mol) is Faraday constant, n is the number of electron moles exchanged for one mole of lithium ions, T (K) is the absolute temperature of the cell, ΔH (J/mol) is the global chemical energy released during the reaction with imposed pressure conditions, ΔS0 (J/mol/K) is the reference free entropy variation. The parameters a and b are empirical coefficients.

The activation and diffusion phenomena can be modelled by dissipative elements R_{act} and R_{diff}. The expressions of these resistors are given starting from the Butler-Volmer equation (not recalled here):

$$R_{diff} = \frac{RT}{\alpha nFI_{lim}} \quad (3)$$

$$R_{act} = \frac{RT}{nFI_0} \quad (4)$$

Where, α represents the charge transfer coefficient (dimensionless), I_0 is the exchange current (A) and I_{lim} is the diffusion current limit (A). These currents depend on the SOC of the cell.

In the model, R_{elec} takes into account the ionic and electronic resistances of the cell. The R_{elec} value is obtained by Electrochemical Impedance Spectroscopy (EIS).

To determine the parameters of the model, an optimization algorithm in Matlab has been used. This algorithm attempts to find a minimum error between the cell voltage obtained by the model and the one measured by experimental tests (a lithium-ion accumulator, 5,8Ah). Figures 3 and 4 present the cell voltage (model and measure) when the cell is discharged at constant current for different C-rates (C/3, C/2). Figure 5 shows the cell voltage (model and measure) for a dynamic discharge current at C/3. The comparison of these results, in static and dynamic modes, allows validating the dynamic model presented in Figure 2.

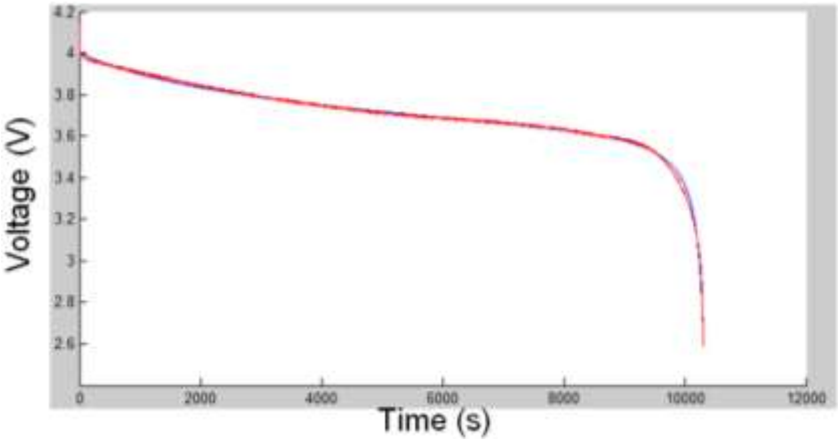

Fig.3: Discharge curves at constant current (C/3).

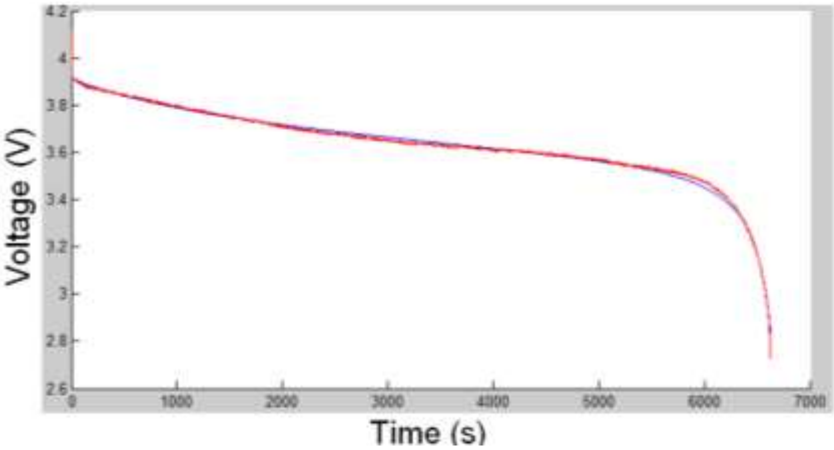

Fig. 4: Discharge curves at constant current (C/2).

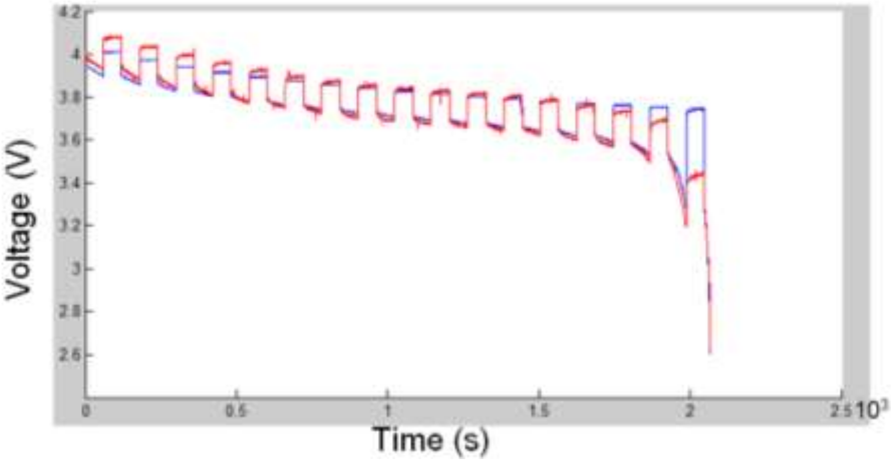

Fig. 5: Discharge curves at dynamic current (C/3).

HYBRIDIZATION OF GAS TURBINE WITH A BATTERY

Figure 6 presents the topology of the hybridization. Two sources (gas turbine and battery) are connected to the embedded network through two power converters. These power converters are simulated by average models.

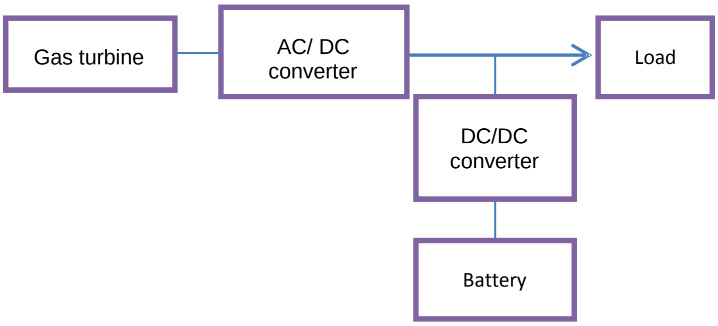

Fig. 6: Hybridization topology.

From this architecture, several energy management strategies have been compared. The hybridization is based on the principle of power sharing where the average power is supplied by the main power source (i.e. the gas turbine) while transient load is fed by the storage device (i.e. the battery). Different technics of power sharing have been investigated. With the present-day electrical power generation of the APU, it appears that a local gain of fuel consumption can be obtained. However, the embedded mass will be higher and neutralizing the overall gain at the aircraft scale.

CONCLUSION

In order to reduce the fuel consumption particularly on ground, the paper has proposed a study hybridization of a gas turbine and a battery. The dynamic behaviours of these two sources have been studied through modelling works. It has been shown that the inertia of a gas turbine is able to answer the intermittent power of the defined load profile. The hybridization of a gas turbine with a battery could be interesting if the intermittent load profiles power become relatively energetic. With the present-day electrical production profiles of the APU, the hybridization is not justified. The conclusion could be different if the APU's functions were extended in the future aircrafts.

This study has also allowed developing a generic tool for modelling multi-sources systems with different elements and different hybridization strategies covering a wide range of possibilities.

REFERENCES

1 N. Chaturvedi, R. Klein, J. Christensen, J. Ahmed and A. Kojic, “Modeling, estimation, and control challenges for lithium-ion batteries”.
2 M. Charkhgardet M. Farrokhi, “State-of-charge estimation for lithium-ion batteries using neural netwarks and EKF”, Industrial Electronics, IEEE Transaction on, vol. 57, n°

12, pp.4178 – 4187, (2010).
3 M. Chen et G. Rincon-Mora, “Accurate electrical battery model capable of predicting runtime and I-V performance”, Energy Conversion, IEEE Transactions on, vol. 21, n° 2,pp. 504 – 511, (2006).
4 L. Ménard, G.Fontès, S.Astier, “Dynamic energy model of a lithium-ion battery”, Mathematics and Computers in Simulation 81 (2010) 327–339.