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Sizing of Hybrid Source Battery/Supercapacitor for Automotive Applications

Laid DEGAA[1,3], Bachir BENDJEDIA[2,3], Nassim RIZOUG[3] and Abdelkader SAIDANE[1]

[1] CaSiCCE Research Laboratory, Ecole Nationale Polytechnique d'Oran, Algeria
Email: Laid.degaa@enp-oran.dz , saidaneaek@yahoo.com
[2] Laboratory of Instrumentation, USTHB University, Algeria
Email: b.bendjedia@yahoo.com
[3] Ecole Supérieure des Techniques Aéronautiques et de Construction Automobile, France
Email: laid.degaa@estaca.fr, nassim.rizoug@estaca.fr

***Abstract*— Energy storage system is a key aspect for the development of clean cars. The work proposed here deals with the sizing of hybrid storage sources composed of a combination of lithium-ion battery and supercapacitors. The batteries are used as a main source and the supecrcapacitors are used as a secondary one. Simulation results show the performance of the gains obtained using the hybrid source in term of weight, volume and cost. In this context, this sizing algorithm finds an "optimal" solution that improves the performance of electric vehicles in term of sizes and aging.**

***Keywords:* batteries; Batteries; Electric vehicle; hybrid source.**

I. INTRODUCTION

The transport sector is responsible for 27% of global CO_2 emissions [1]. It represents one of the main causes of global warming. To reduce these emissions, many policies have been launched to improve energy efficiency of thermal engines [1]. In the field of transport, hybridization aspect was initially devoted to the study of energy management between a fossil source and an electric power source and to improve performances of thermal engines in the presence of an auxiliary electric motor. Potential of this chain is limited by embedded storage system. Lead acid batteries have low power, which has an effect on electric chain during acceleration, deceleration and energy recovery. Furthermore, this technology of batteries has a very low lifetime [2]. This is why, the association of supercapacitors with batteries may solve the problem. The work presented in this paper takes this approach a step further and propose a hybridization of Li-ion batteries with a power source, made of supercapacitors, to drive an all-electric vehicle. A sizing process is proposed to define the hybrid source dimensions and confirm the hybridization benefits in term of weight and cost. Frequency decoupling strategy [2] is used to manage supercapacitors-batteries hybrid sources.

II. ELECTRICAL SOURCES HYBRIDIZATION

Hybridization concepts associate an energy source with a power source so to optimize two sources use. [5] Such solution may lead to a better performance, in terms of cost, size and lifetime, than a system with batteries only, as is the case with most current electric vehicles today.

A. Lithium-ion batteries

Lithium-ion batteries represent the next generation of storage systems for electric vehicles [3]. Many studies have been undertaken by vehicles and batteries manufacturers [4]. There is a strong emulation driven by automotive technological evolution. Different Lithium-ion technologies are available on the market with different performance levels [1].

A Lithium-ion battery has a cathode (metal oxide), an anode (porous carbon) and a conductor electrolyte, Fig.1.

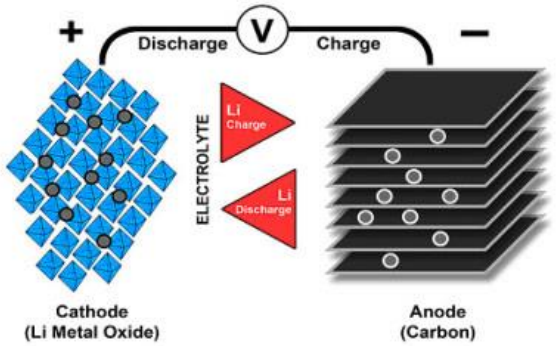

Fig.1 Ion flow in lithium-ion battery [9] .

Acronyms	Ko40HE
costumer	DowKokam
electrodes chemistry(E. negative/E. positive)	Graphite/LiMnNiCo02
nominal voltage, V	3.70
nominal Capacity, Ah	40.00

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Acronyms	Ko40HE
interne resistance, mΩ	0.90
charge/discharge rates, A	40/40
specific energy, Wh/kg	167.25
weight, kg	0.885
volume, l	0.441
cost, €	76.33

Table 1: Ko40HE Li-ion battery specifications [1].

During charge-discharge cycles, ions shuttle between cathode and anode. On discharge, the anode undergoes oxidation or loss of electrons, and the cathode sees a reduction or a gain of electrons. On charge the phenomenon is reversed. In this study, lithium-ion battery uses a manganese (NMC) 40 HED technology (Ko40HE) from battery manufacturer DowKOKAM [9]. Table (1) shows characteristics of this battery.

B. Supercapacitors

A supercapacitor is a type of capacitor that can store a large amount of energy, typically 10 to 100 times more energy per unit mass or volume compared to electrolytic capacitors [13]. It is preferred to batteries owing to its faster and simpler charging, and faster delivery of charge. It is similar to a capacitor except for the bigger area of its plates and the smaller distance between these plates. Its plates are metallic and are soaked in electrolytes and are separated by a very thin insulator [10]. An electric double layer is created in the supercapacitor as opposite charges are formed on both sides of the separator when the plates are charged. This results in a supercapacitor with greater capacitance. In other words, the combination of plates and the larger effective surface area enables a supercapacitor to have greater capacitance and higher energy density. Unlike a battery, a supercapacitor has an unlimited life cycle, with little wear and tear on long-term use. Thus, it can be charged and discharged an unlimited number of times [11].

A supercapacitor has many advantages. It can deliver high power and enable high load currents owing to its low resistance. Its charging mechanism is simple and fast and is not subject to overcharging. Compared to a battery, a supercapacitor has excellent high- and low-temperature charge and discharge performance. It is also highly reliable and has low impedance. However, supercapacitors have some limitations such as cost and high self-discharging. Moreover, unlike regular batteries, it has low specific energy and its use of the full energy spectrum is hindered by linear discharge voltage.[14]

Because of these properties, supercapacitors are used in many applications. They are widely used to deliver power and bridge power gaps. They are a good battery replacement for many settings such as battery-free devices [12].

III. VEHICLE DYNAMIC MODEL

Critical performance characteristics of a vehicle's drive train are maximum speed, maximum slope, and maximum acceleration. Moreover, in the field of electric vehicles, one has to add autonomy as a determinant criterion for performance. Power and energy are imposed by the dynamics of electric vehicle under working conditions (speed cycles, slope profile and vehicle mass) and path to be traveled. Driving cycles are composed of a speed profile and a road slope profile. Currently, different standardized and non-standardized cycles exist (UDC, NEDC, ARTEMIS) [8].

In this study, an ARTEMIS (Asset and Reliability of Transport Emission Models Inventory Systems) cycle is used. Fig.2. shows the urban and road ARTEMIS cycle. The average slope is 2.5%. This cycle has driving dynamics much closer to reality than the UDC and NEDC cycles.

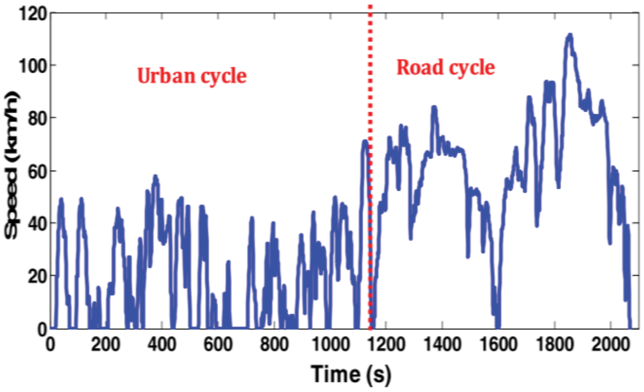


Fig.2 ARTEMIS speed profile.

The load model is developed taking into account the road and velocity profiles. Fig.3 shows forces acting on a vehicle [6],[7].

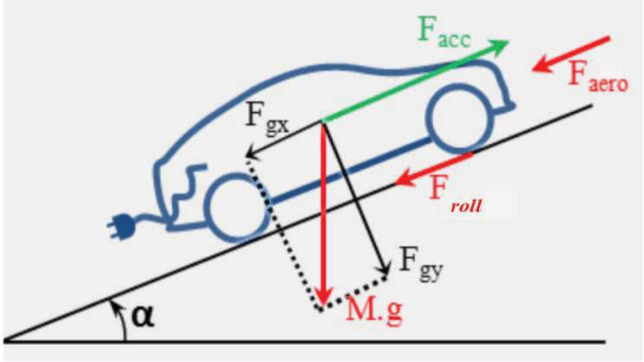


Fig.3: Vehicle dynamic diagram.

Tractive force required for displacement of electric vehicle is the sum of forces resisting advancement and accelerating force. The load force is [3, 4].

$$F_{res} = F_{aero} + F_{roll} + F_{gx} + F_{acc} \tag{1}$$

Where F_{aero} is aerodynamic drag force, F_{roll} is rolling resistance force, F_{gx} is gravitational force and F_{acc} is acceleration force. These forces are detailed in the literature [3].

IV. SIZING A HYBRID SOURCE FOR ELECTRIC VEHICLE

To achieve an autonomy of 150Km, the ARTEMIS driving cycle is repeated seven times. Fig.4 shows the required power and energy according to this driving cycle. Propulsion power is presented positive while power recovered during regenerative braking is negative. Autonomy is measured by electric vehicle energy that is estimated by integrating power demand over time according to equation:

$$E_{cons}(t) = \int_0^t P(t)dt \qquad (2)$$

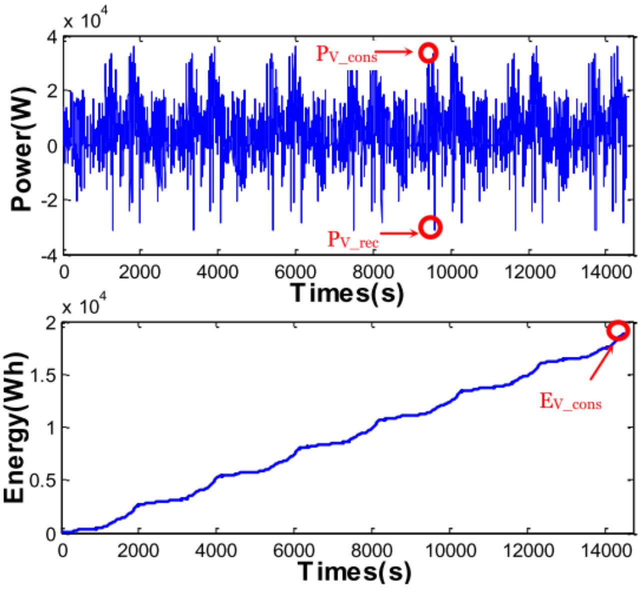


Fig.4: Typical power and energy required to achive ARTEMIS driving cycle.

Three parameters will be used to size the HESS:

- P_{cy_cons}: Maximum power consumed.
- P_{cy_res} : Maximum power recovered.
- E_{conso} : Finale value of energy consumption.

Positive power corresponds to power that propulsion system transmits to the wheels. P_{cy_cons} being the maximum value of this consumed power. P_{cy_res} is the maximum value of power recoverable by the source of energy storage [13].

Parameter E_{conso} represents the maximum value of energy consumed necessary for the autonomy of vehicle.

A. *Sizing battery pack*

The battery pack is sized to provide power for 150 km autonomy according to ARTEMIS driving cycle. To fulfill such configuration, the battery pack has a number of cells in series given by:

$$N_{bat} = \frac{U_{bus}}{U_{cel-bat}} \qquad (3)$$

Where U_{bus} is driving voltage and $U_{cel\text{-}bat}$ is nominal voltage of lithium-ion battery cell

To find the number of branches in battery pack, its energy must be defined:

$$E_{bat} = N_{bat}.N_{bat\_p}.C_{cel\_bat}.U_{cel\_bat}.DOD \qquad (4)$$

C_{cel_bat} is nominal capacity of lithium ion battery cell. DOD is discharge depth, set to 80% in this study.

The number of branches of battery pack is given by:

$$N^{E}_{bat-b} = \frac{E_{bat-cons}}{N_{bat_s}(E_{cel-bat} - a_{bat-cons} w_{cel-bat} 1.4)} \qquad (5)$$

The mass and volume of the battery pack are calculated by:

$$\begin{cases} w_{bat} = (1+\varepsilon_{bat}).N_{bat_s}.N_{bat_p}.W_{cel-bat} \\ V_{bat} = (1+\gamma_{bat}).N_{bat_s}.N_{bat_p}.V_{cel-bat} \end{cases} \qquad (6)$$

$$\varepsilon_{bat} = \gamma_{bat} = 0.4$$

w_{cel_bat} and V_{cel_bat} are respectively the mass and the volume of cells of lithium-ion batteries.

Figure 5 shows the power and energy for a battery Li-ion.

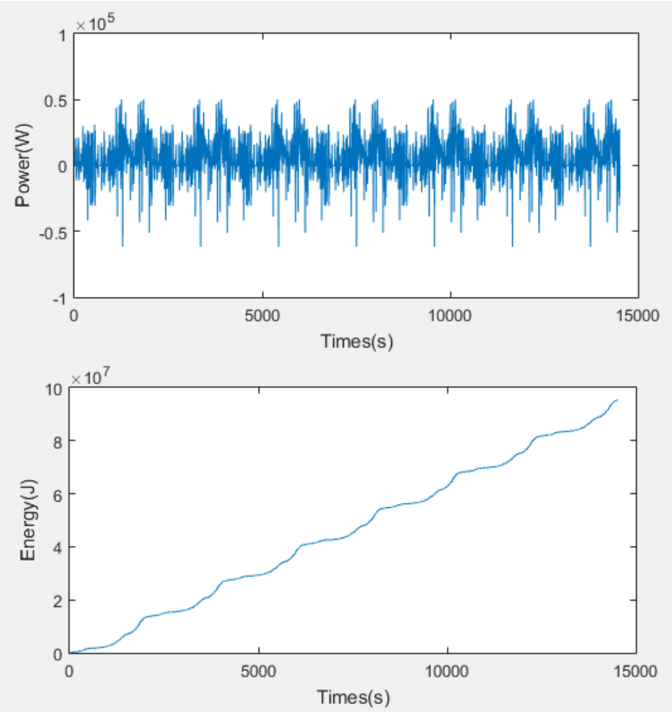


Fig.5: Power and energy for mono source system (battery)

B. *Sizing supercapacitor pack*

Voltage of a pack of supercapacitors has to be between a maximum voltage U_{Bus} and a minimum voltage equal to ½.U_{Bus} ; Energy represents 75% of energy stored in supercapacitors. The useful energy available in a pack of N_{sc_s} elements in series and N_{sc_p} branches is expressed by:

$$N_{sc-p} = \frac{8.\Delta E_{sc}}{3.U^2_{sc-max}} \cdot \frac{N_{sc}}{C_{cel-sc}} \qquad (7)$$

C_{cel_sc} and U_{sc_max} are respectively nominal capacity and maximum voltage of a supercapacitor element.

The mass and volume of the pack of supercapacitors are calculated by:

$$\begin{cases} w_{sc} = (1+\varepsilon_{sc}).N_{sc_s}.N_{sc_p}.W_{cel-sc} \\ V_{sc} = (1+\gamma_{sc}).N_{sc_s}.N_{sc_p}.V_{cel-sc} \end{cases} \qquad (8)$$

$$\varepsilon_{bat} = \gamma_{bat} = 0.4$$

w_{cel_sc} and V_{cel_sc} are mass and volume of supercapacitor cell, respectively.

Figure 6 shows the power and energy for a supercapacitor.

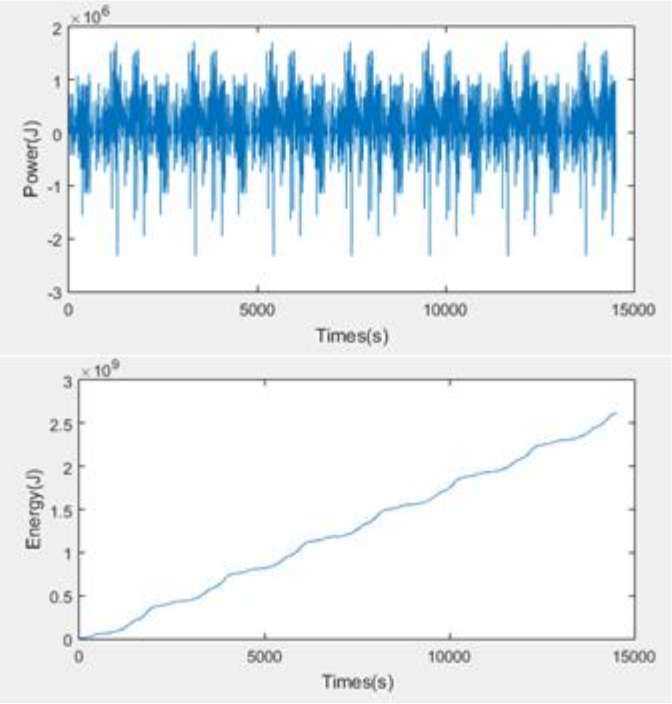


Fig.6. Power and energy for mono source system (supercapacitor)

V. POWERING ELECTRIC VEHICLES WITH HYBRID ENERGY SOURCES

Sizing hybrid energy sources with respect to power is very restrictive and offers few degrees of freedom for optimization. Furthermore, it is virtually impossible in most cases to recover all braking energy due to technological constraints (particularly low battery charging). Thus, in order to fully recover this energy and to exploit characteristics of energy storage systems to best advantage, hybridization is the best solution. The general idea of this principle of hybridization of energy storage systems is based on respecting the intrinsic nature of energy and power sources. On this basis we will size the components of the hybrid system considering that the role of the battery pack is to ensure autonomy (energy source) and that the presence of supercapacitors meets the dynamic requirements of the EV peaks of power at acceleration and braking).

The objective of the Energy Management Strategy is to define the mission of each source. The used strategy in this work is based on a frequency splitting. Its principle is illustrated in Figure, the power (P_V) required to propel the electric vehicle is filtered by a low pass filter. The part made of low frequencies will be provided by the battery (P_{bat}), and the harmonic high frequency portion is returned to the supercapacitor pack (P_{SC}). So the cutoff frequency value that determines the mission of each source. This value is related to the characteristics of the storage system sources. Figure 7 shows the energy management strategy for the hybrid system.

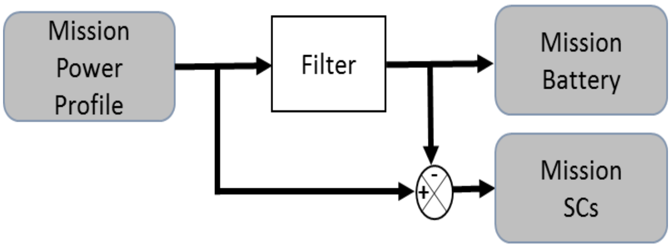
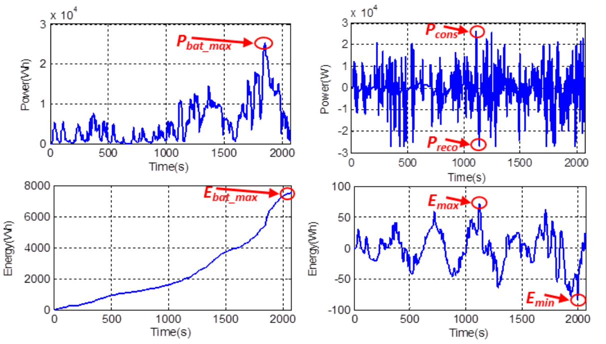


Fig.7: Principle of the energy management strategy



Profile de Mission de la batterie

Profile de Mission des supercondensateurs

Fig.8. Power and Energy Mission profiles of each source

VI. THE IMPORTANT AND DIFFICULT TASK IN SIZING PROCESS

The determination of the cells number of batteries and supercapacitors is the main objective of the sizing process. Indeed, this number depends on many parameters related to the component mission profile as the maximum and minimum energies (E_{max}, E_{min}), the maximum consumed and recovered powers (P_{cons},P_{reco}) (see Figure.8). These parameters represent the maximum stresses that can be ensured by the battery and supercapacitors packs

VII. RESULTS

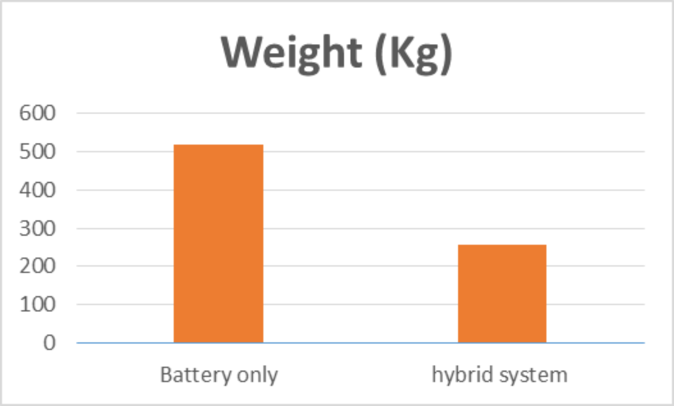
This section is dedicated to the presentation of the results of the ESS sizing.

The Fig.9 shows the sizing results of the hybrid source and the batteries only.

As shown in fig.9.a, the weight of the ESS is lower in case of hybrid source with 55% compared to the batteries only. This confirms that the ESS weight is affected by the hybridization.

As shown in Fig.9.b, the ESS volume is lower too in case of hybrid source by 45%, this rate is obtained because of the high specefic energy of the batteries and the highspecific power of the supercapacitors.

The ESS cost is enhanced by 44% in case of using hybrid source (see Fig.9.d). this can confirm that the supercapacitors can enhance greatly the ESS sizes and addionally the cost too.



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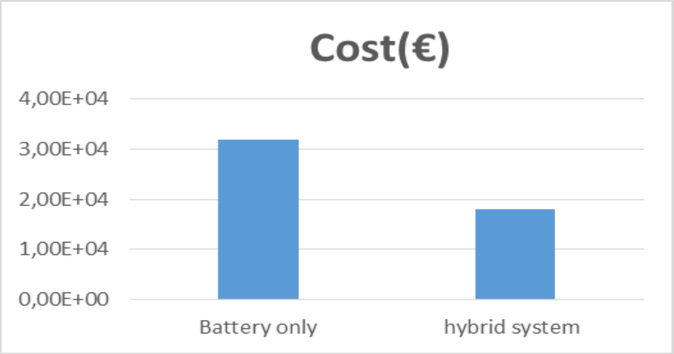

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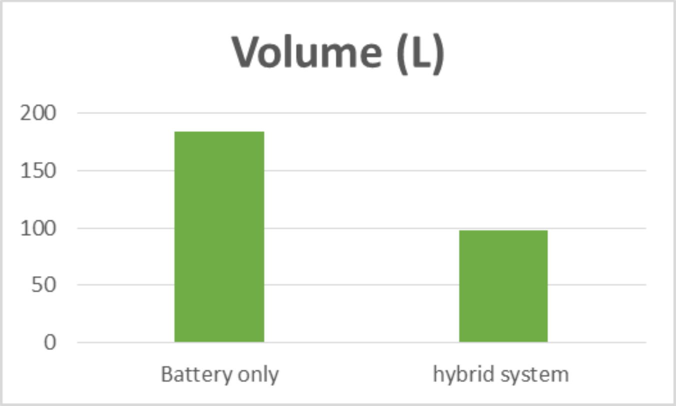

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Fig 9. Sizing results of the mono source and hybrid source

VIII. CONCLUSION

In this paper, the battery / supercapacitor hybrid energy storage system was designed and compared with a battery only supply in term of weight, cost and volume.

The obtained results show that the choice of the hybridization is a key issue to improve the source size and its cost. Using Scs as a secondary source can enhance greatly the ESS caracterestics at the same time where considerable gains are obtained compared to the batteries only use. The gains are evaluated to 55 % in term of weight, 45% in term of volume and 44% in term of cost .

As a result, it is noted that the hybridization of batteries with the SCs is an interesting solution to make up the Energy Storage System for automotive applications.

REFERENCES

[1] R. Sadoun, “Intérêt d’une Source d’Energie Electrique Hybride pour véhicule électrique urbain – dimensionnement et tests de cyclage,” Thèse Ecole Centrale de Lille, 2013.

[2] Q. Badey, “Étude des mécanismes et modélisation du vieillissement des batteries lithium-ion dans le cadre d ’ un usage automobile,” Thése, Université Pari-Sud 2012.H. Poor, *An Introduction to Signal Detection and Estimation*. New York: Springer-Verlag, 1985, ch. 4.

[3] R. Sadoun, N. Rizoug, P. Bartholomeus, B. Barbedette, and P. Le Moigne, “Optimal sizing of hybrid supply for electric vehicle using Li-ion battery and supercapacitor,” in 2011 IEEE Vehicle Power and Propulsion Conference, 2011, pp. 1–8..

[4] T. Mesbahi, N. Rizoug, P. Bartholomeus, and P. Le Moigne, “Li-Ion Battery Emulator for Electric Vehicle Applications,” 201 IEEE Vehicle Power and Propulsion Conference (VPPC), pp. 1–8, Oct. 2013.

[5] [5] W. Lajnef, “Modélisation des supercondensateurs et évaluation de leur vieillissement en cyclage actif à forts niveaux de courant pour des applications véhicules électriques et hybrides,” Thése, L’Université Bordeaux 1,2006.C. J.Kaufman, Rocky Mountain Research Lab., Boulder, CO, private communication, May 1995.

[6] L. Allegre, A. Bouscayrol, and R. Trigui, “Influence of control strategies on battery/supercapacitor hybrid Energy Storage Systems for traction applications,” in 2009 IEEE Vehicle Power and Propulsion Conference, 2009, pp. 213–220.

[7] R. Sadoun, N. Rizoug, P. Bartholomeus, B. Barbedette, and P. Le Moigne, “Influence of the drive cycles on the sizing of hybrid storage system battery-supercapacitor supplying an electric vehicle,” in IECON 2011 - 37th Annual Conference of the IEEE Industrial Electronics Society, 2011, no. 2, pp. 4106–4112.

[8] R. Sadoun, N. Rizoug, P. Bartholomeüs, B. Barbedette, and P. L Moigne, “Optimal Sizing of Hybrid Supply for Electric Vehicle Using Li-ion Battery and Supercapacitor,” 2011.

[9] P. Nelson and S. C. Ave, “Advanced Lithium-Ion Batteries for Plugin Hybrid-Electric Vehicles.” Argonne National Laboratory, Transportation Technology R&D Center,2007.

[10] W. Lajnef, “Modélisation des supercondensateurs et évaluation de leur vieillissement en cyclage actif à forts niveaux de courant pour des applications véhicules électriques et hybrides,” Thése, L’Université Bordeaux 1,2006.

[11] A. Hammani, R. Sadoun, N. Rizoug, P. Bartholomeus, B. Barbedette, and P. Le Moigne, “Influence of the management strategies on the sizing of hybrid supply composed with battery and supercapacitor,” in 2012 First International Conference on Renewable Energies and Vehicular Technology, 2012, pp. 1–7.

[12] J. Nzisabira, Y. Louvigny, and P. Duysinx, “Comparison of ultra capacitors, hydraulic accumulators and batteries technologies to optimize hybrid vehicle ecoefficiency,” 2009 International Conference on Power Engineering, Energy and Electrical Drives, pp. 353–358, Mar. 2009.

[13] M. Thele, S. Buller, D. U. Sauer, R. W. De Doncker, and E. Karden, “Hybrid modeling of lead–acid batteries in frequency and time domain,” Journal of Power Sources, vol. 144, no. 2, pp. 461–466, Jun. 2005.

[14] N. Rizoug, P. Bartholomeüs, and P. L. Moigne, “Modeling and Characterizing Supercapacitors Using an Online Method,” vol. 57, no. 12, pp. 3980–3990, 2010.