Energy Secondary Source Technology Effect on Hybrid Energy Source Sizing for Automotive Applications

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Abstract— A comparative study of two Hybrid Energy Storage Systems (HESS) for automotive applications in terms of weight, volume and cost is undertaken. Main source is a High Energy (HE) density battery while secondary source can be an Ultra High Power (UHP) battery or a Super capacitor (SC). Simulation results show that gains in weight and volume are obtained when HESS uses an UHP secondary source instead of a SC. Drive range is found to have no effect on HESS sizing. Sizing algorithm is used to find an "optimal" solution that improves electric vehicles performance.

Keywords: ***Batteries; Electric vehicle; hybrid source, Super capacitors, Ultra High power.***

I. INTRODUCTION

Transport sector is responsible for 27% of global CO_2 emissions [1]. It represents one of the main cause 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, energy sources hybridization was initially devoted to study 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 systems. 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 low lifetime [2]. Lithium-ion battery has high energy density, high thermal performance and is recyclable. Several technologies exist with differences being in positive electrode composition.

Based on the presentation of on-board energy sources for electric vehicle applications, we present the problem of energy storage as a technological lock limiting the development and marketing of electric vehicles in terms of cost, autonomy and life time. Current Energy Storage Systems have limitations that do not meet the needs of applications in some cases. Hybridization of energy sources and the right combination of sources are believed to be the technological lock to undo and is the subject of this article.

II. TECHNICAL SPECIFICATIONS

2.1 Driving Cycle (mission)

The ARTEMIS cycle is widely used in ESS sizing and aging tests [1, 5, 6]. Three real-world driving cycles (urban, rural road and motorway) have been built-up to be representative of actual conditions of vehicle driving and to reproduce different driving conditions [6]. In this paper, only urban and rural road driving cycles are considered as shown in Fig.1. These cycles allow emulating the vehicle running a distance of 22 Km. Since in this study considered drive range is 700 Km, these cycles are repeated 32 times to achieve the needed autonomy.

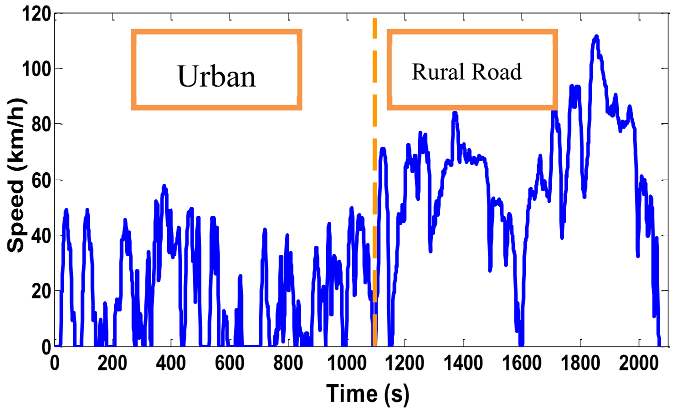


Fig.1 ARTEMIS driving cycle.

2.2 Vehicle parameters (mission):

A dynamic model of vehicle, developed at ESTACA'LAB under Matlab-Simulink software, is used to estimate the power and energy needed for proposed profile [7]. Parameters of bolero vehicle are shown in Table I.

Vehicle power and energy consumptions are estimated by integrating net forces acting in opposite direction of vehicle movement, namely aerodynamic drag force F_{aero}, rolling resistance force F_{roll}, gravitational force F_{gx} and time derivative of momentum in moving direction times vehicle's speeds over time. Power consumption can be written as [7]:

$$P = \left(M\frac{dV_{veh}}{dt} + F_{aero} + F_{roll} + F_{gx}\right)V_{veh} \qquad (1)$$

$$\text{With} \begin{cases} F_{aero} = 0.5\,\rho\, S\, C_x\, V_{veh}^2 \\ F_{roll} = M\,g\,(\,C_0 + \,C_1\,V_{veh}^2) \\ F_{gx} = Mg\sin(\alpha) \end{cases} \qquad (2)$$

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

$$F_{res} = F_{aero} + F_{roll} + F_{gx} + F_{acc} \qquad (3)$$

Where F_{acc} is acceleration force. These forces are detailed in the literature [3].

TABLE I. VEHICLE CHARACTERISTICS

Parameters	**value**
Vehicle mass (kg)	860
Frontal area (m^2)	2.75
Air density (Kg /m^3)	1.2
Penetration coefficient	0.3
Rolling resistant coefficient	0.008

Fig.2 shows required power and energy required to achieve an ARTEMIS driving mission profile. Positive power values indicate the power propulsion needed at wheel's level and (P_{con}) is the maximum power consumed. While negative values represent power recovered during regenerative braking. (P_{rec}) is maximum value of power that can fully or partially be recovered.

(E_{con}) parameter is finale value of energy consumption that is needed to run the distance of 700 Km. Maximum power and maximum energy parameters change with driving patterns conditions, and will be used to size the Hybrid Energy Storage System (HESS).

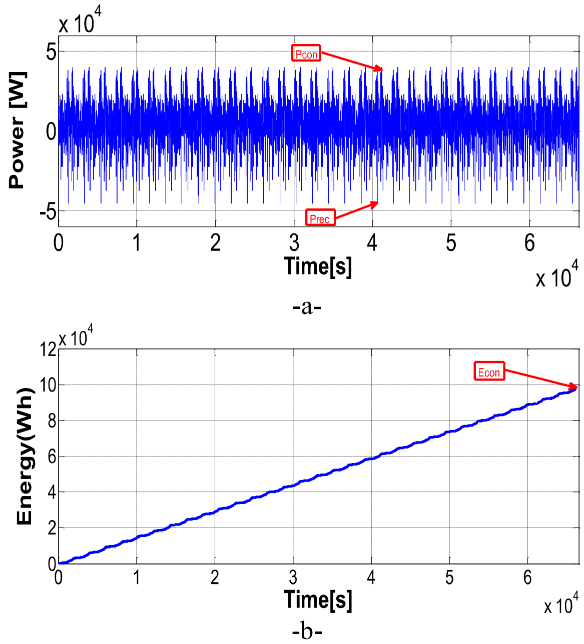


Fig.2 Typical power (a) and energy (b) required to achieve an ARTEMIS driving mission.

III. HYBRID SOURCE SIZING

To demonstrate the importance of hybridization, sizing is undertaken on the combination of two different sources, a high energy Li-ion source and a high power Li-ion source. In this study, sizing covers different parameters such as masses, volumes, costs, autonomy and so on. It will also be shown that power batteries are needed when high energy batteries can't supply the vehicle for long ranges without hybridization.

KOKAM CELLS SPECIFICATIONS [13]

KOK UHP	KOK 40HE
C_{elb} = 0.45 AH	C_{elb} = 40AH
U_{elb}= 3.7 V	U_{elb}= 3.7 V
I_{elb_Dis} = 22.5 A	I_{elb_Dis} = 40 A
I_{elb_C} = 22.5 A	I_{elb_C} = 40 A
W_{elb} = 0.014 Kg	W_{elb} = 0.885 Kg
V_elb = 0.036 L	V_elb = 0.441 L
Cost = 1.24 Euros	Cost = 20.63 Euros

For example to achieve 150Km autonomy, ARTEMIS driving cycle is repeated seven times. Fig.3 shows required power and energy to achieve this driving cycle. Propulsion power is presented positive while power recovered during regenerative braking is negative. Electric vehicle autonomy is measured by integrating power demand over time according to equation:

$$E_{cons}(t) = \int_0^t P(t)dt \qquad (4)$$

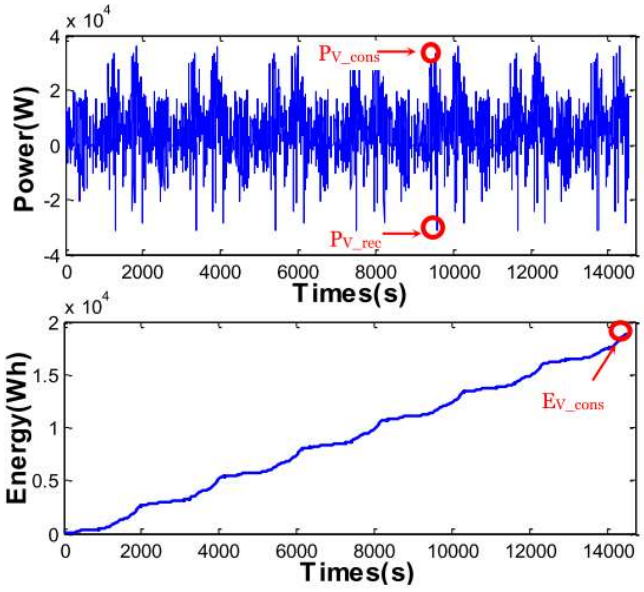


Fig.3: Typical power and energy required to achieve 150 Km autonomy according to ARTEMIS driving profile.

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 transmitted to the wheels. P_{cy_cons} is the maximum value of this consumed power. P_{cy_res} is the maximum value of power recoverable by energy storage source [13].

E_{conso} represents maximum consumed energy necessary for vehicle's autonomy.

A. Battery Sizing

The number of cells that compose the battery pack is related to battery mission profile. Effective energy stored in a battery depends on the depth of discharge according to:

$$E_{bat} = N_{cel\_bat} * C_{cel\_bat} * U_{cel\_bat} * \text{DOD} \qquad (5)$$

where:

- N_{cel_bat} is the number of cells
- C_{cel_bat} is the cell capacity
- U_{cel_bat} is the cell voltage

Depth Of Discharge (DOD) of batteries considered in this work is 20%. This DOD value improves greatly batteries pack lifespan, hence the whole system.

The number of battery cells can be found from:

$$N_{cel\_bat}^{E_{bat\_cons}} = \frac{E_{bat\_cons}}{DOD*C_{cel\_bat}*3600*U_{cel\_bat}} \qquad (6)$$

Another issue is that the battery must recover the braking power P_{bat_rec}. In this case the cell number is expressed using charge power (P_{cel_Char}) as follow:

$$N_{cel\_bat}^{P_{bat\_rec}} = \frac{P_{bat\_rec}}{P_{cel\_Char}} \qquad (7)$$

B. Supercapacitors Sizing

Compared to batteries, super capacitors have a higher specific power but they have a smaller specific energy [6]. Other advantages are high cycling capability and recycling without pollutants. Super capacitors fill in the gap between capacitors and fuel cell [1, 13]. Super capacitors are able to provide very important power needed for short durations (acceleration phases), and store the energy recovered during braking phases. These two high charge/discharge powers conditions are the factors to optimize when sizing super capacitors [15]. The number of super capacitors cells N_{sc} is calculated with respect to energy peaks (E_{sc_max}) using the following formula:

$$N_{sc} = \frac{8\, E_{sc\_max}}{3*3600*U_{cel}^2*C_{cel}} \qquad (8)$$

It is recommended to know the real size and shape of the ESS for embedded automotive applications. For this reason, assembly package of secondary source is taken to constitute 40% of global size [6, 8]. In this study, weight ratio (in %) of additional elements of assembly and protection circuits is considered. Hence, weight of battery pack are expressed as

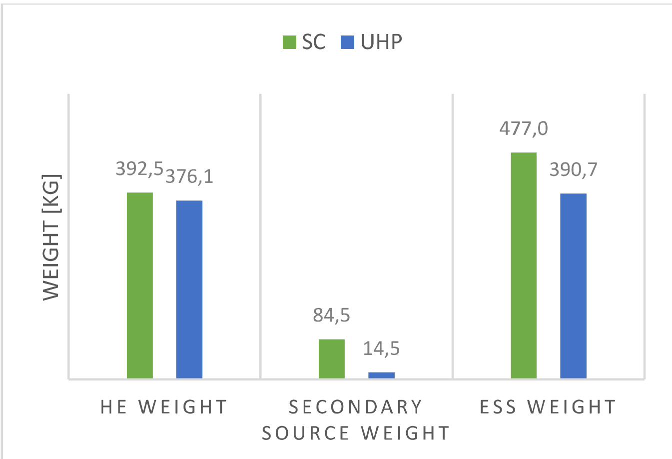
$$W_{bat} = (1.4 * N_{cel\_bat} * W_{cel\_bat}) \qquad (9)$$

where:

- W_{bat} is batteries pack weight
- $W_{cel\_bat:}$ is weight of each battery cell.

IV. Results and Discussion

This section presents and analyzes sizing results of HESS using two technologies for secondary source.



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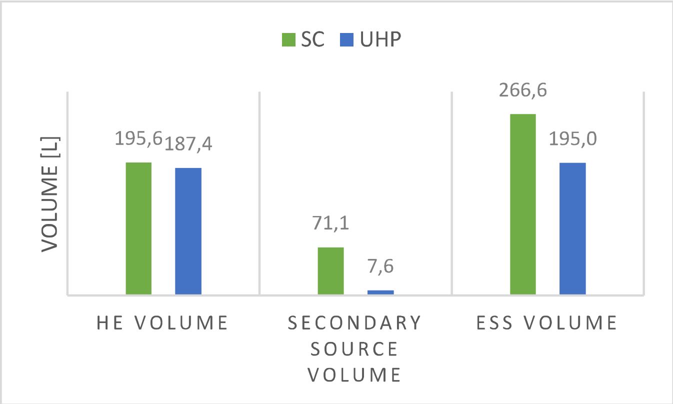

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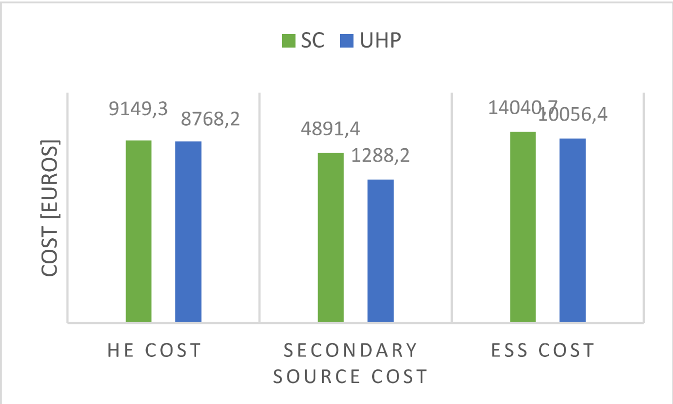

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Fig.4 Sizing results for 300 km drive range: -a- weight, -b- volume, -c- cost

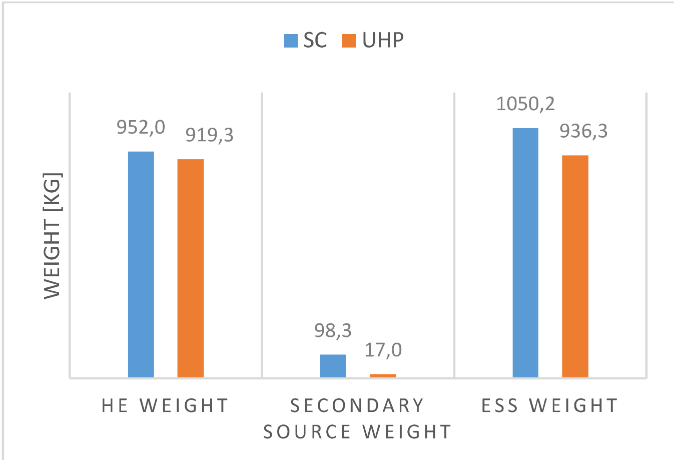
Fig.4 shows sizing results in terms of weight, volume and cost for 300 km drive range. Fig.4.a indicates that main source (HE) weight is slightly affected by secondary source choice because the same energy is needed to ensure autonomy. Secondary source weight is lower by **80%** for UHP compared to Super Capacitors (SC) because of UHP higher energy density. For this reason, ESS weight is lower by **20%** when using such batteries.

As shown in Fig.4.b, ESS volume is lower by **27%** when using UHP bateries as secondary source instead of SCs. This rate is obtained because of high specefic energy of UHP batteries compared to supercapacitors. On the other hand, ESS cost is increased by **73%** when using UHP batteries. Consequently, UHP batteries enhance ESS characteresetics and vehicle performance.

Fig.5 shows sizing results in terms of weight, volume and cost for 600 km drive range. As shown in Fig.5.a, ESS weight is lowered by 12% when using UHP technology. Main source weight is little affected by secondary source technology as mentioned previously. Fig.5.b shows ESS volume affected by secondary source technology because specific powers of two technologies are not identical. Using UHP technology, ESS volume is enhanced by 18%.

The use of SCs penalises ESS cost by 65% (see Fig.4.c). Note that major cost is affected by secondary source and SC cost makes ESS cost higher.

Above HESS characteristics are affected directly by secondary source technology, but not by drive range of electric vehicle.



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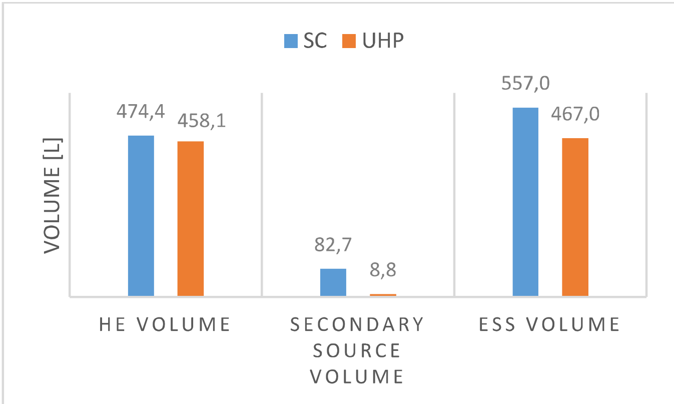

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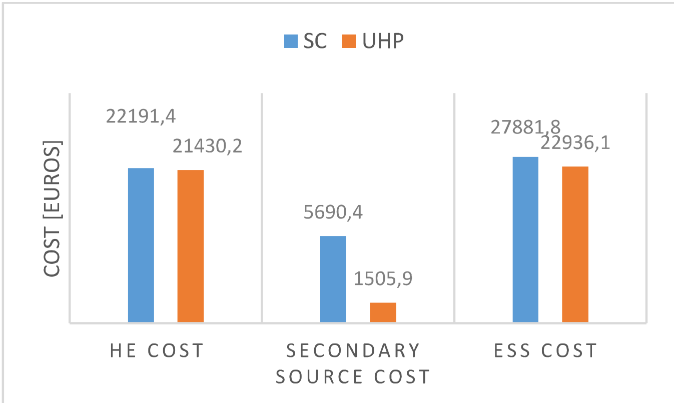

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Fig.5 Sizing results for 600 km drive range: -a- weight, -b- volume, -c- cost

V. CONCLUSION

Hybridization benefits are confirmed using sizing algorithm and UHP batteries. The choice of secondary source takes into account weight, volume and cost. When secondary source is an UHP battery instead of a Supercapacitor, HESS decrease in weight to about 20% and in volume to about 27% but its cost