Power management strategies of hybrid storage system suppling electric vehicle

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***Abstract*— Battery electric vehicles (BEV) initially appeared as a promising solution against climatic disasters due to petroleum vehicles and the continuous growth in energy demand for road transport. However, their weak autonomy combined with too high a cost slowed down their development in the world market. However, a second transition to multi-source electric vehicles which consist of a set of Energy Storage Systems (ESSs), may be possible solutions to improve the vehicle's autonomy and the duration of battery life by significantly reducing polluting emissions to the environment. In fact, this paper presents a hybrid SSE which is mainly based on High energy lithium-ion (Li-ion) batteries and High power batteries for powering an all-electric vehicle. This hybridization of a main High energy Li-ion battery source with the secondary High power batteries source adds greater HEV autonomy but it increases the complexity of the Energy Management System (EMS). In this work, the main objective is designed to simulate the strategies based on deterministic rules like the filtering method (MF) and the Limitation method (ML) for running electric vehicle with hybrid source in real time. Strategies ML and MF were chosen in the first place thanks to their simplicity in time integration real but unfortunately these techniques have no control over the behavior of the High power batteries during the rolling cycle. For this an improvement of these three strategies was introduced by integrating a technique of control of the state of charge "Control SOC" of this secondary source in order to follow the behavior of the High power batteries along the conduct of the driver in order to ensure loading the High power batteries at the end of each cycle. These strategies of the proposed energy management system have been successively validated by experimental tests for an urban-type rolling cycle (ARTEMIS) using the Matlab-Simulink.**

Keywords— Electric vehicle with hybrid source, High energy lithium-ion (Li-ion) batteries, High power batteries, State of charge, Limitation method, Filtering method, Control SOC method

I. INTRODUCTION

The question of the energy crisis, as well as climate change, has made a lot of anchors this last decade[1]. According to an inventory made in 2019 by the International Energy Agency, and with 23% of the contribution, transport is the second source of greenhouse gases after producing electricity and heat, followed by industry With 20%. In the first 23%, three quarters are caused by road transport, especially with the growing dependence on fossil fuel in this industry and most others. This issue provides a strong driving force in developing green and sustainable transportation systems that have boosted the electrification of vehicles worldwide. In a non-far future, this new transport mode will replace fossil fuel vehicles, and one of the major components of an electric vehicle is its storage system [2]. The management of energy flows in a hybrid storage source Electric vehicle is always a delicate subject, as there are countless ways to proceed. The main questions to be asked are[3]:

- How to manage these flows "optimally"?
- What is the right balance between advantages/disadvantages?

In our case, the addition of an auxiliary source with a specific high power like high power batteries, allows to decrease strongly the current stresses on the batteries and thus increase the overall performance of the storage source (duration of life, performance, dynamics, autonomy, etc...)[4]. In addition, the presence of this energy source additional functionalities, particularly because of its reversibility. It then becomes possible to recover the entire braking energy[5]. This distribution must satisfy the power demand of the electric motor and comply with energy constraints of the storage system. This hybrid system requires an appropriate energy management strategy to maximize the potential of different sources and in order to efficiently use the on-board energy[6]. It can be based on deterministic rules or not, but also on objective functions (lifetime of the battery, driving comfort, fuel consumption of the vehicle, etc...). Many work was done on the subject[7].

These strategies can be classified into two main categories:

- Strategies based on predefined rules
- Strategies based on optimization

The Fig.1 summarizes the relationship between design basis and hybrid source management. The input variable of this process is the power profile of the electric vehicle and the characteristics of batteries HE and batteries HP[8].

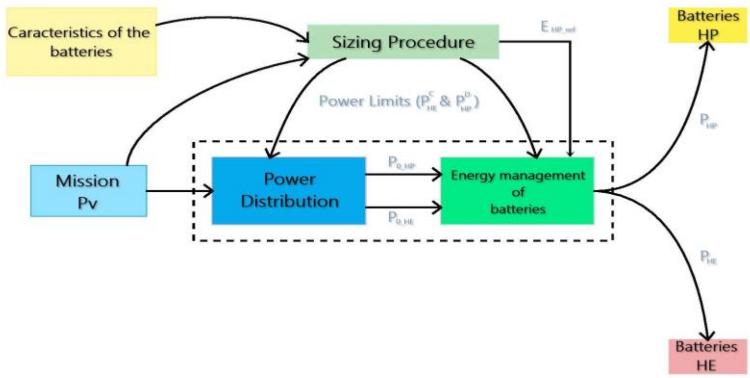


Fig. 1. Energy management for hybrid energy

The output variables are the power instructions distributed on both sources.

In this thinking context, this paper will discuss the specifications needed in our study as a first part; they will detail into the used vehicle dynamic model and the storage system besides their modelling. After that, we'll discuss the results we've had from simulations work, followed by results discussion and a conclusion.

II. Specifications

A. Vehicle Model

The power can be calculated based on the type of vehicle used. The amount of mechanical energy consumed by a vehicle when driving a given driving pattern depends on three effects:

- Aerodynamic friction losses;
- Losses by rolling friction;
- The energy dissipated in the brakes.

From Fig.2 the vehicle model can be described using Newton's second law [2].

Where 'Fa' is the drag force, 'F_r' is the rolling friction, 'F_g' is the force caused by gravity when driving on non-horizontal roads, 'F_d' is the disturbing force that sums up all other effects, and 'F_t' is the pulling force which depends on speed and acceleration.

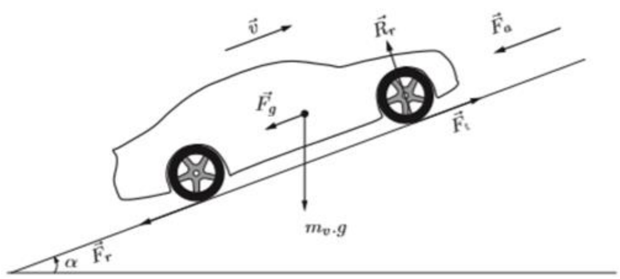


Fig. 2. Acting forces on the vehicle.

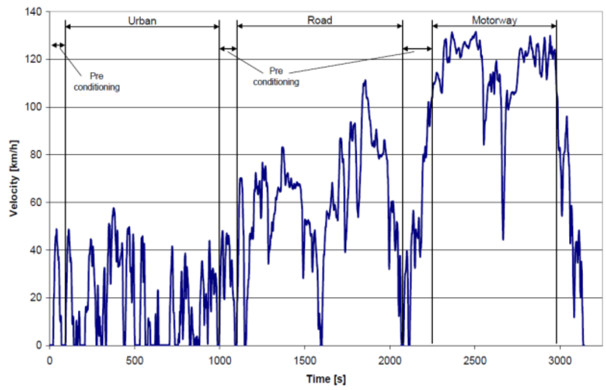


Fig. 3. Artemis Cycle

B. Mission

To validate our system, we must test under different circumstances that could be faced in an automotive application as a test mission. We chose the Artemis Driving cycle. This cycle is based on a statistical study carried out in Europe as part of the Artémis project. It is composed of 3 different configurations, plus an additional variant: urban cycle, rural, highway 130 km/h and highway 150 km/h as we can observe in the Fig.3[9].

C. Li-ion batteries and cells selected for study

The following Table.1 summarize the main characteristics of the two type of battery elements Li-ion selected for our study:

- One High Power Density (HP).
- The other with High Energy Density (HE).

TABLE I. KOKAM CELLS SPECIFICATIONS[10]

Parameters	***Kokam HE***	***Kokam HP***
Capacity C_elb (Ah)	40	13
Voltage U_elb(V)	3.7	3.7
Discharge current I_elb_Dis (A)	40	104
Charge current I_elb_C (A)	40	39
Weight W_elb (kg)	0.885	0.325
Volume V_elb(L)	0.441	0.174
Cost (Euros)	20.63	30.36

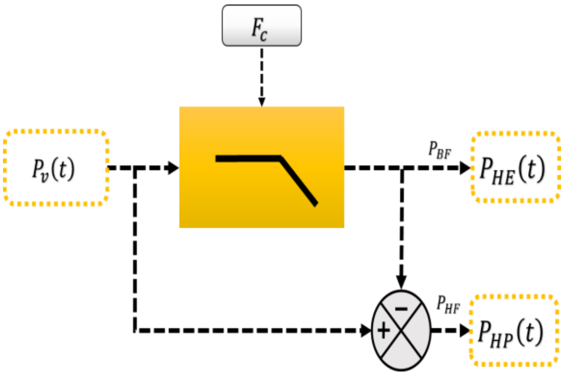


Fig. 4. Principle of the frequency energy

III. Results and discussion

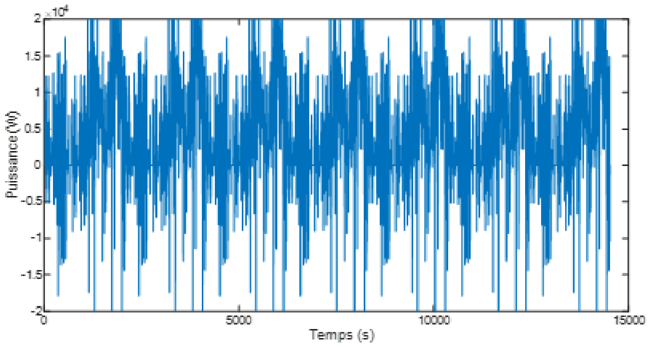
A. Strategies based on frequency energy

Frequency energy management consists of making sources complementary energy and power (battery HE/ battery HP) taking into account the characteristics intrinsic to each source to ensure the overall mission of the vehicle. The guiding idea of this strategy consists of distributing the low-frequency components of the traction power to the power source (P_{HE}) and high frequencies at the power source (P_{HP}).

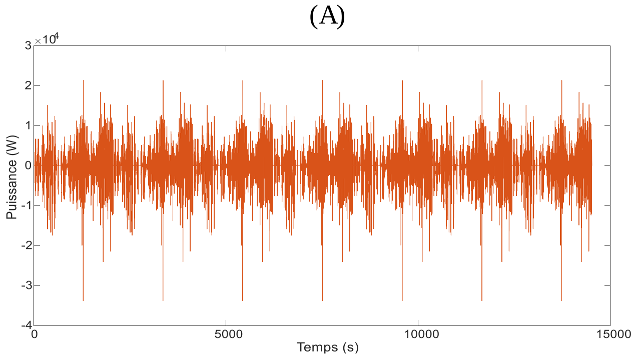
Fig. 04 illustrates the principle of frequency energy management. The power (PV) required for the propulsion of the electric vehicle is broken down into two parts by the low pass filter[11].

- Application

The mission profiles (power and energy) of the batteries HE/HP, given by the filtering, are shown in Fig. 5 It can be seen that the power recovered by the batteries HE is zero and that the batteries HP have, most of the time, the task of recovering this energy. In addition, the high powers returned to the batteries HP are not necessarily high frequency harmonic powers.



(A)



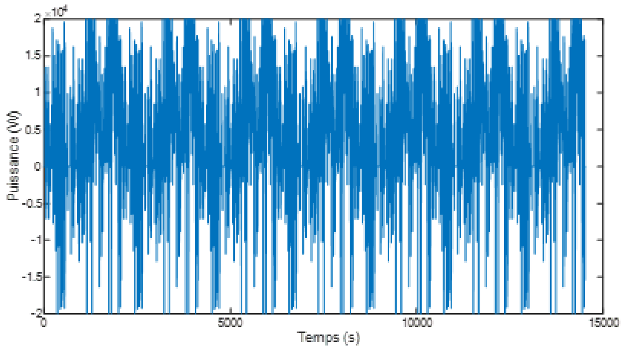
(B)

Fig. 5. Power and energy profiles from filtering strategy. (A) batteries HE, (B) Batteries HP strategy

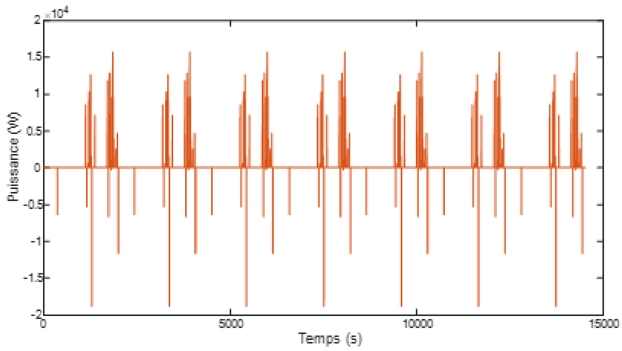
B. Strategies based on power limitation

This strategy uses a classic power saturation approach. It consists of limit the charging and discharging power of the HE battery in advance over the entire route considered. The use of power limits then makes it possible to maintain the state of charge HE battery power within an acceptable range and provides an additional degree of freedom to help to optimize the operation of the hybrid storage system. Indeed, the choice of the limits of battery power is generally related to the average mission power and the internal characteristics of the two components[12]. Fig 6 presents energy management in a hybrid source where the instantaneous power is broken down into two missions. This example of power profiles shows that the energy management algorithm limits the battery power in both phases (charge / discharge). The HP battery then ensures the power difference between the mission of the vehicle (Pv) and that of the battery (P_{HE})[13].

- Application



(A)



(B)

Fig. 6 Power and energy profiles from limitation strategy. (A) batteries HE, (B) Batteries HP

C. *Strategy based on power limitation with SOC control*

To meet the same objectives imposed for the power limitation method, namely the use of batteries to ensure autonomy and HP batteries for power peaks. These should be recharged to energy balance at the end of the driving cycle[14]. To do this, modifications have been made to the frequency management strategy, by integrating battery power saturation and management of the state of charge of the batteries HP (see Fig. 7)[15].

The HP batteries would have the possibility of discharging on the batteries and vice versa to regain energy balance[16].

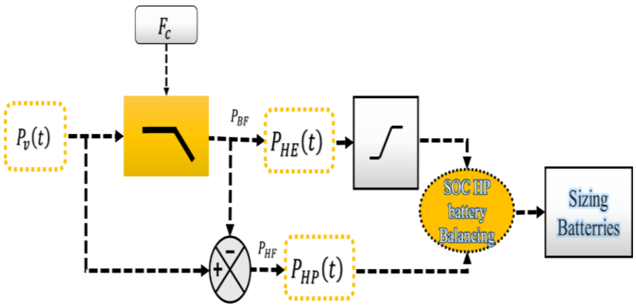
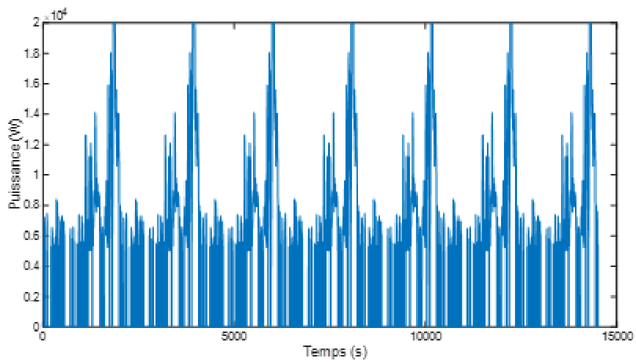


Fig. 7. Principle of the power limitation with SOC control strategy

➢ Application



(A)

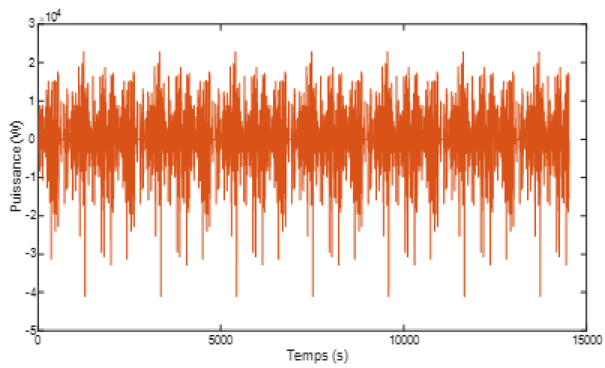
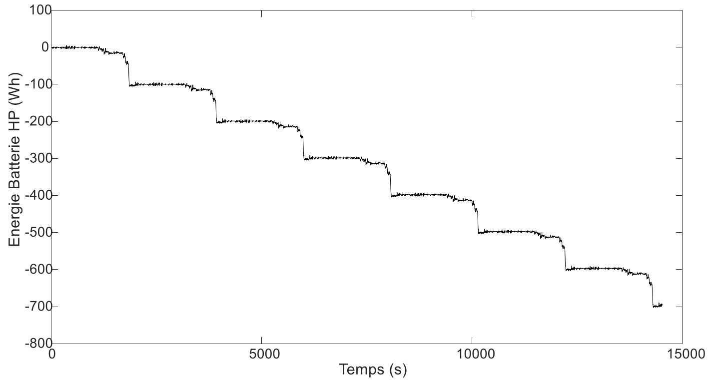
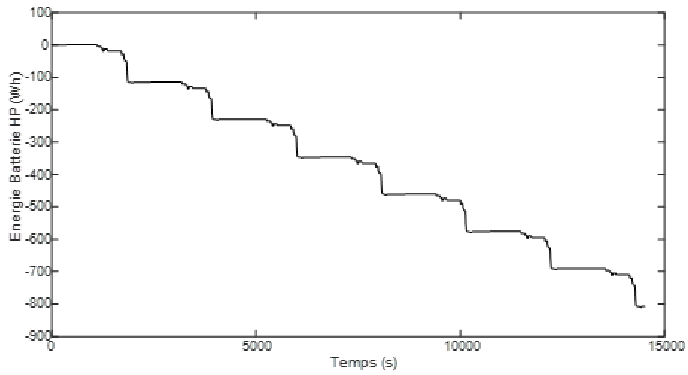


Fig. 8. power and energy profiles from limitation strategy. (A) batteries HE, (B) Batteries HP



(A)



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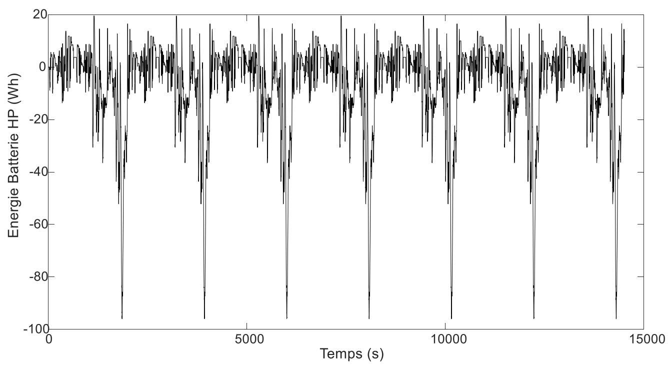

(C)

Fig. 9. State of charge . (A) frequency , (B) limitation (C) SOC control

showing us the evolution of the powers obtained with the different management methods for the two HE and HP battery technologies. In the case of power limitation, the constraints on the power battery are very low, however the energy state of this battery decreases with use and it does not return to the initial state (Fig. 9) . With the filtering method, we notice an increase in the constraints on the power battery with an average smoothing of the power of the HE battery. With the method developed, we have a maximum smoothing of the power of the He battery which will reduce the constraints of this component and we also notice that the energy state of the HP battery always returns to the initial state.

IV. Conclusion :

This article presents three power management strategies for a hybrid energy storage system powering an electric vehicle that mainly includes a primary high-energy type Li-ion battery and another high-power battery as a secondary source. In this context, we applied ML and MF strategies based on deterministic rules currently used to ensure constraint sharing between the two sources. On the basis of these two strategy variants, a "Control SOC" method has been developed based on an adaptation of the battery limit powers according to the state of charge of the high-power battery. The simulation results using MATLAB-Simulink, demonstrate the interest of the strategy developed, with a gain of 21.4% on the effective power and a reduction of 25% on the ampere-hours exchanged by the primary source. This stress reduction can significantly improve the life of the storage system.

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