BATTERY AND SUPER CAPACITORS-BASED SINGLE CONVERTER HYBRID POWER PACK ENERGY MANAGEMENT

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Abstract.
Dealing with the energy management of a single converter hybrid power pack involving battery and super capacitor, the real condition simulation and the preliminary experimental results have been hereby given. Through of a suitable management of both super capacitors (Scaps) state of charge and the dc bus voltage, smoothed power demand is assigned to the battery pack, whereas high frequency power demand is managed by the Scaps pack. Because military vehicle application is the target of the related application, security-based constraints namely battery pack temperature, current and voltages thresholds, are taken into account. The developed energy management is applied through 16-bits Microchip microcontroller dsPIC33EP512MU810 by means of CAN and CANopen communication. The presented results need to be refined owing to the sampling time issues of the used CAN bus frames.

1. Introduction

The presented work is performed in the framework of a partnership project involving E4V (Energy For Vehicle) and FEMTOS-ST (Franche-Comté Electronics Mechanics Thermal and Optics - Sciences and Technologies). This research is funded by the French Government Armament Procurement Agency (DGA – Direction Générale de l'Armement). The main purpose is developing a control card intending to manage energy within a hybrid power pack in order to propel a vehicle. The theoretical description, of the developed energy management strategy, has already been presented in [1]. In fact, it is a one converter hybrid power pack of battery and Super capacitors (Scaps).

One or two converters-based such a hybrid system has already been developed involving fuel cell and Scaps [2-14]. Whether the one converter-based energy management [2-3,12-13] or the two converters ones [4,6,14], it's often dealt with ensuring smooth behaviour on the terminal of the low frequency devices like fuel cell or the medium frequency ones like batteries. The main benefit of one converter network is consequently a saving purpose (reduce the hybrid power pack price). Therefore, the most used energy management principle tends to apply charge sustaining strategy to the Scaps by smoothing energy of the battery [2-3,4,6,12-13,14]. Such an approach requires three nested control loops: an inner current control loop, then an inner voltage control one and an outer voltage control loop called compensation loop. This latter one serves to perform charge sustaining behaviour of the Scaps by pursuing its reference voltage value.

In this work, with the hybrid power pack involving one converter, it is expected to also operate the Scaps in charge sustaining mode by smoothing the battery power. Compare to the previous performed works [2-3, 12-13] which are implemented with real-time Dspace controller board with 25-kHz sampling frequency, our application uses CAN bus-based CANopen protocol communication. In such a system like ours with different sampling time of the involved devices, the control become more complex than the former applications. The highest sampling time is 100Hz and the lowest is 10Hz. This kind of application based only on communication through CAN bus is carried out in this paper.

The paper is organized as follow: firstly, the experimental text bench is presented before provide the CAN bus and the control structure characteristics. Afterwards, simulation results based on real application characteristics (devices data transmission sampling time, the control signal one, the real response time of the control system) are provided. Finally, before the conclusion some preliminary experimental results are given.

2. Experimental setup

The experimental test bench has been carried out in the laboratory (FEMTO-ST\FC LAB's site) as shown in the figure 1. Using MPLABX 2.6 Microchip software, the performed control algorithm is written in the *dsPIC33EP512MU810*. Then through the CAN bus, data flow are exchanged between the devices and the control card.

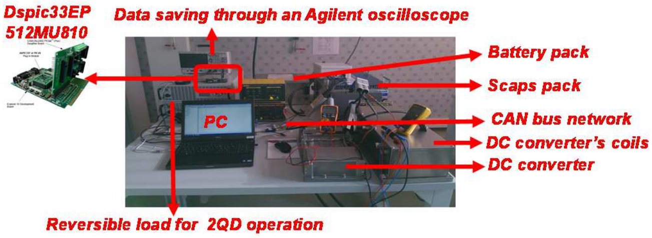

Fig. 1. Electrical network of the system

The hybrid power pack network and the related control structure aiming at matching the control target is shown on figure 2 [1]. It can also be found in reference [1] parameters calculation of the nested loops based on PI controller.

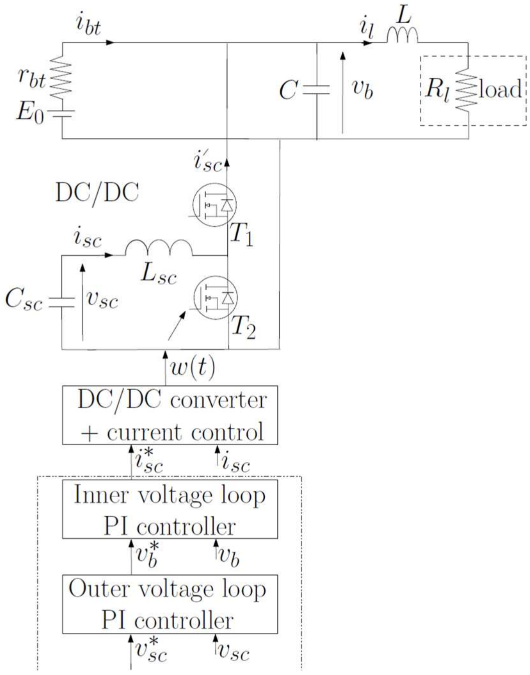

Fig. 2. Nested control loops

3. The Control of the system

The Nested control loops can be performed based on IP or PI discretized controllers (Fig. 4). PI discretized controller structure has been used in our system. Equations (1)-(3) present the pseudo-code of the PI controller, whereas equations (4)-(6) show the IP ones.

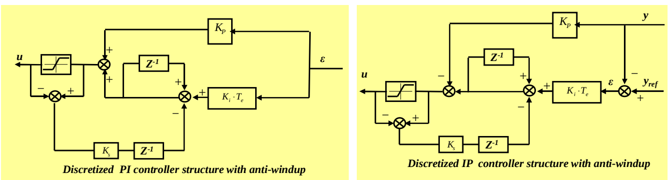

Fig. 3. Discretized PI (left) and IP (right) controllers' structures

For IP controller,

$$\varepsilon_t = y - y_{ref} \quad (1)$$

$$s = s + K_i \cdot T_s \left(\frac{\varepsilon_t + \varepsilon_{t-1}}{2}\right) + \left(u_{(t-1)} - u_{(t)}\right) \quad (2)$$

$$u_{(t-1)} = s - K_p \cdot y \quad (3)$$

For PI controller,

$$\varepsilon_t = y - y_{ref} \quad (4)$$

$$s = s + K_i \cdot T_s \left(\frac{\varepsilon_t + \varepsilon_{t-1}}{2}\right) + \left(u_{(t-1)} - u_{(t)}\right) \quad (5)$$

$$u_{(t-1)} = s + K_p \cdot \varepsilon_t \quad (6)$$

The sampling data of table 1 are useful for the inner and the outer voltages (v_{sc}, v_b) loops and the compensation of the battery current (i_{bt}); they are accordingly measured and transmitted through their CAN frames. It can be seen that these data are endowed with different characteristics related to their precision and their sampling time.

Table 1. Data acquisition characteristics.

Measures	Sampling [ms]	Precision	Numbering system
v_{sc}	54.2	$\pm$0.05V	Float
v_b	109	$\pm$0.01V	float
i_{bt}	109	$\pm$0.1A	Float

Regarding the set point current value (Table 2), it appears that to the DC-DC converter, it is provided 10ms sampling time integer as current reference value. While we would need a precision to the hundredth of the value of the current. It is a constraint from which we cannot undo. This might introduce some inaccuracies whether on Scaps voltage management or on battery pack set point voltage management.

Table 2. Set point variable characteristics.

Set point variable	Sampling [ms]	Precision	Numbering system
i_{scref}	10	$\pm$1A	Integer

The table 3 shows the controllers' parameters. Thanks to all the provided parameters (from table 1 to table 4) the system model is simulated. Then, preliminary experimentation has been performed.

Table 3. Controllers' coefficients.

	Inner loop	Outer loop	Sampling [ms]
Proportional coefficient	1.7184	-0,375	10
Integral coefficient	103.1	-0,0114	10

Table 4. CAN bus features.

	values
Baud rate	250 kps
Data frames on the CAN bus	10
Minimum sampling time	0,5Hz
Maximum sampling time	10Hz

4. The simulation and experimental trials

As a result of the foregoing, the real conditions simulations have been performed.

4.1 The simulation trials

A pulse generator profile with 25s period, 50% of the period with an amplitude of 20A is applied as the load's current. A nominal operation is consequently modelled according to the current limitation in charge $i_{bt\_max\_ch}$ = *-10A* and the current limitation in discharge $i_{bt\_max\_dis}$ = *30A*. The figure 4 gives the results.

One can see that, the results at very high frequency (Fig; 4 (b)) should be refined because of the high dynamic power seen by the battery pack. However, this is due to the sampling time of the CAN bus communication and the related convergence response time of the nested loops controllers. Moreover, in the view of the industrial partner (E4V Electric for Vehicle), the provided battery pack (Lithium iron phosphate batteries pack) could overcome such instantaneous power peak (from the data sheet 240A during 40s is tolerated). Further work should deal with this issue to smooth energy on the terminal of the battery pack at high frequency.

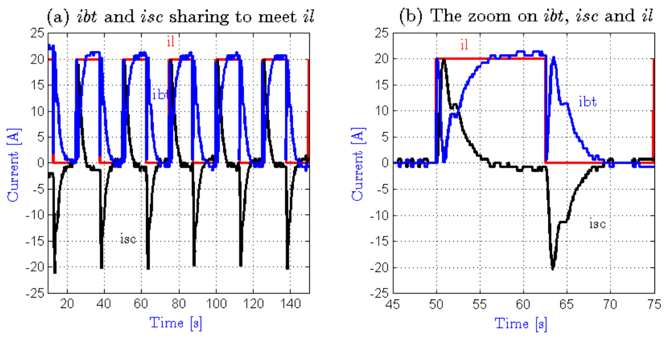

Fig. 4. Real condition simulation results

4.2 The preliminary experimental trials

This section is going to justify the expected behaviour of the implemented energy management strategy. In addition, the results will be analysed and both the strengths and the drawbacks of such an approach will be shown up. The three operating modes will be introduced: Normal operating mode in which the limitation bounds in charge and in discharge are not reached, the limitation mode in discharge and the limitation one in charge.

Considering both the battery pack and the scaps pack temperatures, the security-based thresholds are taken into account. The operating condition range of the temperatures is from -20°C to 45°C for the battery and from -40°C to 65°C for the Scaps. Throughout the experimental trials, because of the low current amplitude (less than 50A) the temperatures remain roughly constant. These thresholds are integrated in the implementation so that outside these bounds the emergency stop is launched.

As for the current and voltage thresholds, the principle is explained in [1] and is implemented in the control card. The proper voltage thresholds management implies the proper management of the current ones. Therefore, for succinctness reason, only the current limitation will be emphasised on afterwards.

4.2.1 Normal operating mode

It is worth remarking that, the experimental results showing the waveforms of the battery and Scaps packs, match very well with the simulation results (Fig. 5 (a) and (b)).

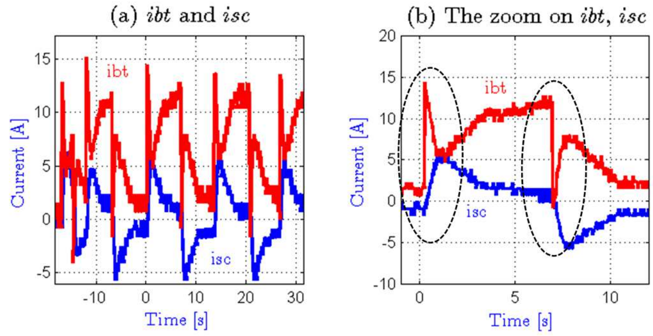

Fig. 5. Normal operating mode result

The load in the simulation case is a pulse of 20A. The battery current limitation bound in discharge being slightly set at 15A, it can be seen that any current limitation occur during this behaviour as shown on the Fig. 5. However, high frequency current peaks are seen by the battery pack as explained earlier. Except this issue, the control card behaves as hoped.

In fact, the control key variables are gathered in the table 1 (*vb* and *vsc*) with their related acquisition sampling time. It emerges that over 10ms sampling time, the control is not refined at high frequency.

4.2.2 Battery current limitation mode: operating mode in discharge

This section deals with the battery pack security-based current limitation. The current bound in discharge is 15A and a load pulse of 20A is applied as shown on Fig. 6(a).

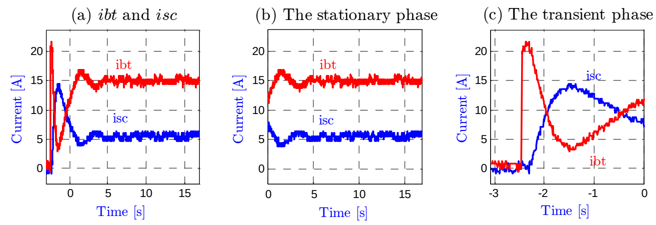

Fig. 6. Current limitation mode in discharge: (a) ibt and isc, (b) the zoom in the stationary phase, (c) the zoom in the transient phase

The current is suitably managed and after a slight overtaking due to the two nested PI controllers, a steady state of the current limitation is reached. The Scaps pack therefore assists the battery pack by supplying the 5A remaining current as expected (Fig. 6 (b)).

The transient period is highlighted by the zoom on Fig. 6 (c). Before the Scaps react to the current set point sent by the converter, the battery pack undergoes the load profile high frequency component. Afterwards, the system converges toward the desired behaviour point. From Fig. 6 (c), it emerges that during a current drop, the current threshold in discharge is overcome. This is the main drawback of this control in the current state.

4.2.3 Battery current limitation mode: operating mode in charge

As the behaviour is in discharge, it is likewise in charge (Fig. 7). In stationary phase (Fig. 7 (b)), the limitation is observed but not in transient one (Fig. 7 (c)). The same analyses in discharge are also available in charge.

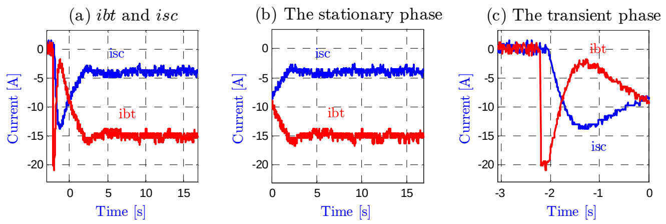

Fig. 7. Current limitation mode in charge: (a) ibt and isc, (b) the zoom in the stationary phase, (c) the zoom in the transient phase

6. Conclusions

Based on the single converter hybrid power pack of battery and super capacitors packs, the energy management strategy is implemented. In spite of the different sampling time (data transmission sampling time on the CAN bus) of the devices, the suitable response time allowing satisfactory control of the power flow has been performed experimentally. Unfortunately, to obtain some proper results a sampling time of at most 10ms should be applied to the measured data instead of 100ms inducing unrefined smoothing on the terminal of the battery pack at high frequency. In further work, the presented results will be refined by integrating some independent measurements with sampling time of at most 10ms (through the same CAN bus).

According to these satisfactory results (based on the battery pack allowable stress tolerance), different restrictive mission profiles could afterwards be applied. Further hybridization benefits analysis after a result refining step could be done.

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