BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LVII (LXI), Fasc. 6, 2011
Secţia
ELECTROTEHNICĂ. ENERGETICĂ. ELECTRONICĂ

HYBRID ELECTRICAL ENERGY STORAGE FOR EMBEDDED VEHICULAR POWER SYSTEMS

BY

ŞTEFAN BREBAN[*] and M.M. RĂDULESCU

Technical University of Cluj-Napoca

Received, May 31, 2011
Accepted for publication: July 18, 2011

Abstract. The embedded vehicular power systems are developing fast due to electrification of the transportation sector. Hybrid-electric vehicles, full electric vehicles, airplanes, ships, high-speed trains, all share a common issue – the embedded electrical power system. The aim of this paper is to comparatively present two configurations of the embedded electrical power system for vehicular applications, the first one being a simpler one, and the second one incorporating a fuzzy-logic supervizor. The simulation results show the advantages of using the fuzzy-logic supervision structure.

Key words: energy storage; embedded power systems; fuzzy logic.

1. Introduction

Numerous arguments to increase efficiency on every level of energy consumption are advocated: exhaustible raw material for energy generation, high costs of exploitation, pollution agents due to burning of carbon based fuels and the famous CO_2 green gas effect that mostly concerns us nowadays. All these issues are pushing researchers to find more ways to reduce consumption by increasing efficiency. One of the solutions is to electrify the transportation sector, as being considered the worldwide biggest consumer and polluter. Electrification in this area comes naturally when we look at the advantages: greater efficiency, increased reliability, better dynamics and sometimes smaller

---

[*] Corresponding author: *e-mail*: Stefan.breban@mae.utcluj.ro

costs (Zhang *et al*., 2009). One of the most important elements of an embedded vehicular electrical power system is the energy storage device. This element plays different roles depending on the application: main power source, auxiliary power source, power smoothing or power peak shaving.

This paper presents a comparison between two configurations for the considered power system (Fig. 1).

2. Studyied System

Depending on the destination and application of the embedded electrical power system, several solutions can be considered. In Fig. 1, a typical embedded electrical network is presented. The main power source consists of a Li-Ion battery, being presently one of the best solutions for electric or hybrid-electric vehicles (Vazquez *et al*., 2010; Chen & Pan, 2007). The bidirectional loads represent the sum of electrical or electromechanical systems from electric machines to auxiliary systems. Several electromechanical systems are capable to pass from motor to generator mode, and thus to recover electrical power. In this case, the storage and dissipation systems are the consequent choices in order to increase the efficiency of the power system but also to maintain its stability.

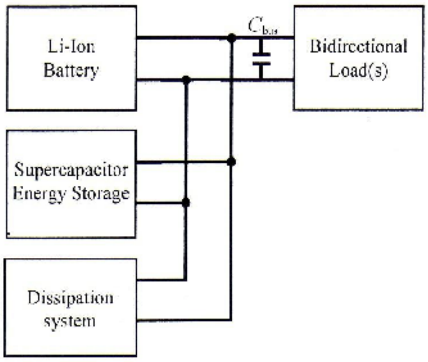


Fig. 1 – Scheme of an embedded electrical power system for vehicle application.

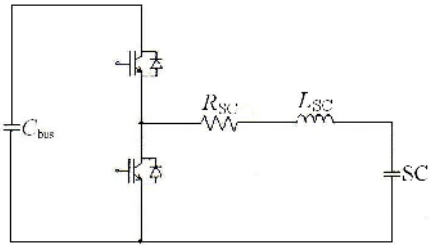


Fig. 2 – Supercapacitor interface to DC bus.

The main advantages of Li-Ion battery technology are high energy-to-weight ratios, no memory effect, and a low self-discharge in comparison to other solutions like Ni/Cd or Ni/MH. Electrochemical double-layer capacitors (EDLCs) or supercapacitors work in much the same way as conventional capacitors, so that there is no ionic or electronic transfer resulting in a chemical reaction. In other words, energy is stored in the electrochemical capacitor by simple charge separation.

The first system architecture is developed as follows: the Li-Ion battery is directly connected to the dc bus, and thus, the dc-link voltage will vary depending on the battery state of charge (SOC); the supercapacitor (SC) energy storage device is connected to the DC-link by means of a bidirectional buck-boost converter (Fig. 2). The values for passive components are: R_{SC} = 0.12 Ω, L_{SC} = 37 mH, C_{bus} = 100 mF. The SCs have a nominal voltage of 48.6 V and an equivalent capacitance of 165 F. They are considered fully charged at 48 V and fully discharged at 24 V. The nominal voltage of the battery is of 48 V.

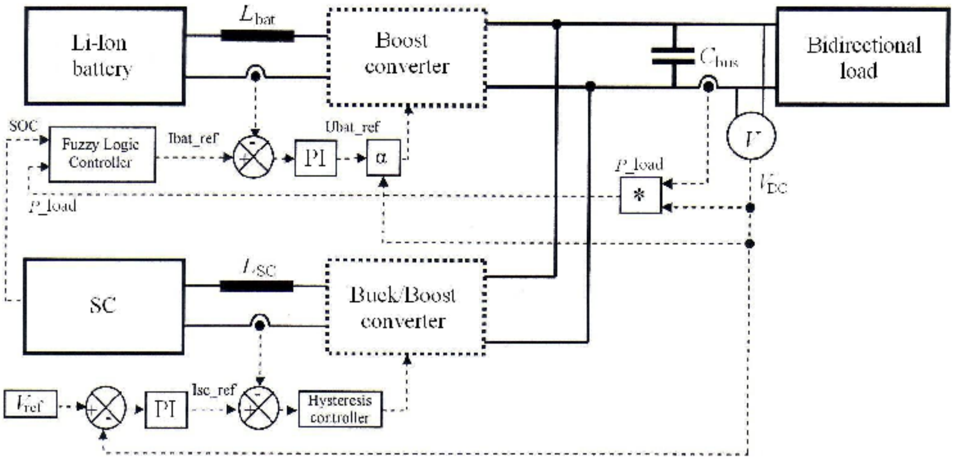


Fig. 3 – Embedded power system control scheme.

The second system architecture considers the same structure as in the first case, but the Li-Ion battery is connected to the dc-link bus by means of a boost converter (Fig.3). In this case the power drawn from the battery is directly controlled, and the DC-link bus can have a different preset value. The values for the passive components on the side of the boost converter are: R_{bat} = 0.3 Ω, L_{bat} = 70 mH. The SC and battery currents are controlled using Proportional-Integral (PI) controllers (Fig. 3).

3. Simulation Results

These two configurations were simulated in Matlab/Simulink environment, using SimPowerSystems Toolbox and Fuzzy-Logic Toolbox as well. The simulations were performed for a time-interval of 20 s, by considering the load power profile of Fig. 4. In Fig. 5, the fuzzy-logic supervision surface is presented. The reference battery current is determined depending on the SC SOC and the load power. The system behavior for the two configurations is presented in the next figures. In both cases, one condition was always considered: the battery should not recharge during normal operation. This condition was adopted to reduce the charge–discharge cycles, and thus to extend the battery life. Also, in the second configuration, as the battery current is controlled, a 0.5 s time-constant was considered to further reduce the sudden changes in current reference.

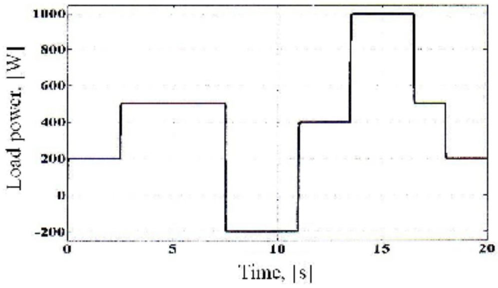


Fig. 4 – Load power profile.

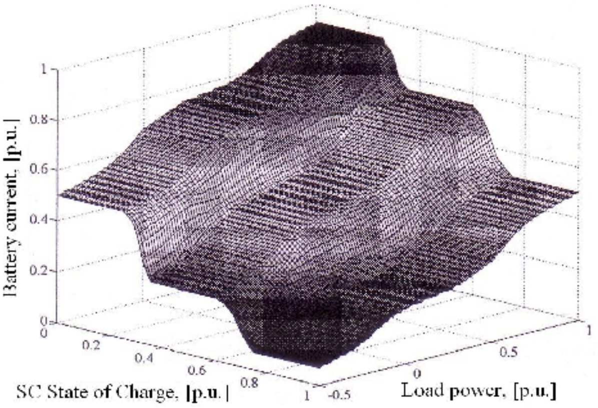
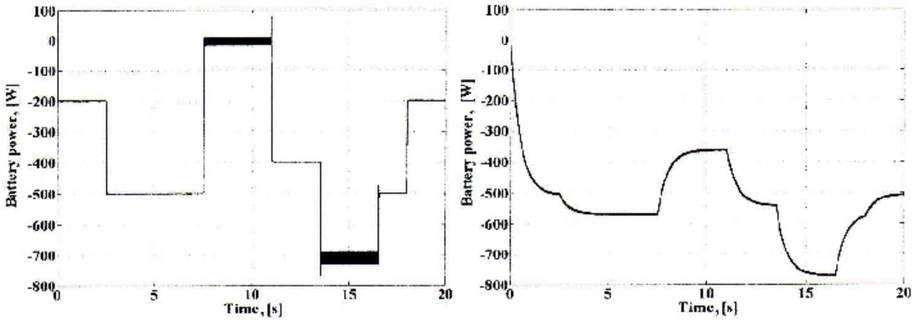


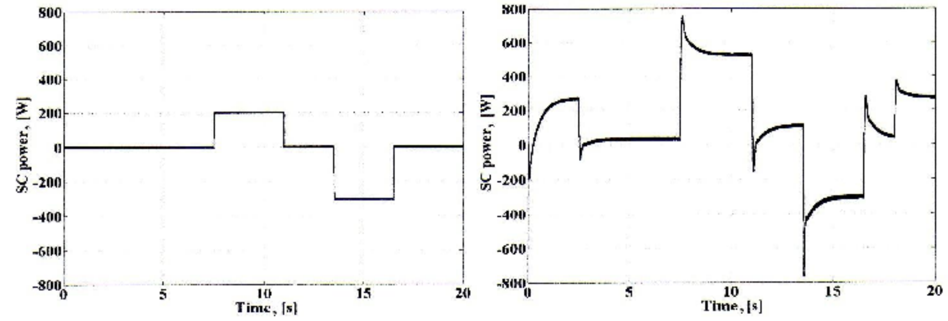
Fig. 5 – Battery current reference depending on SC state of charge and load power.

Figs. 6 *a*, *b* show the power output of the Li-Ion battery for the two configurations considered. It is to be seen that in the second configuration, the power drawn from the battery is smoother. In Figs. 7 *a*, *b*, the SC power in the two cases is presented. For the first configuration (Fig. 7 *a*), the SCs are used only to recover the returned power and to compensate the high power demand from the loads. In the second case, the SCs are also used to compensate the power transients. In this way one can continuously and softly discharge the Li-Ion battery, thus reducing the charge–discharge cycles, the peak power drawn by the loads and prolonging her period of use. The dc-link voltage value, in Fig. 8 *a*, is imposed by the Li-Ion battery. In the second configuration, one has chosen to set a reference of 150 V. In this case, the SCs are controlling the voltage value with the help of a simple PI controller. Figs. 9 *a*, *b* and 10 *a*, *b* show the SOC for the battery and SC. It can be seen that for the second case the battery discharge is more constant, and that the SCs have the tendency to charge. This is an indirect effect of the fuzzy-logic supervision structure that will charge the SC to a superior energy level.



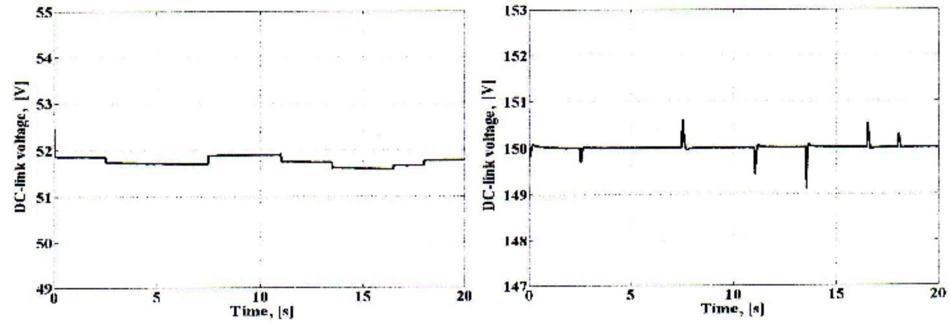
a *b*

Fig. 6 – Li-Ion battery power.



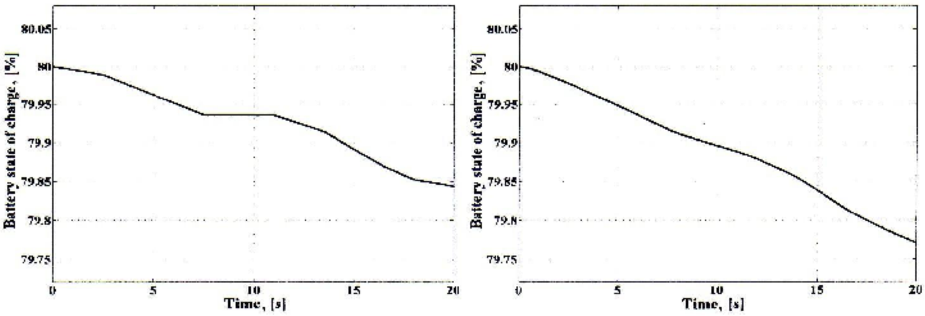
a *b*

Fig. 7 – Supercapacitor power.



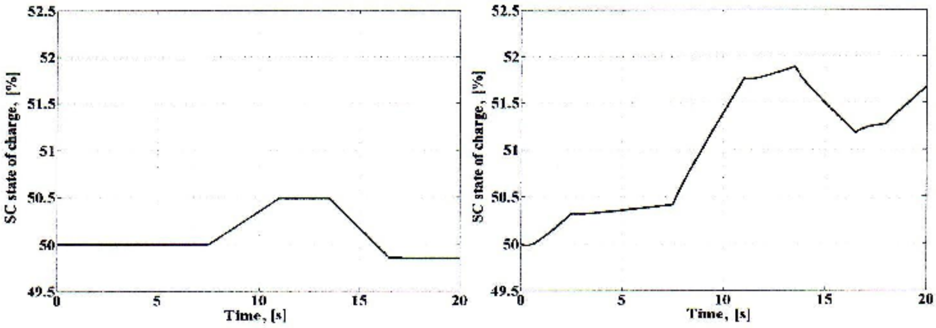
a *b*

Fig. 8 – DC-link voltage.



a *b*

Fig. 9 – Battery state of charge.



a *b*

Fig. 10 – Supercapacitor state of charge.

4. Conclusions

Two configurations for an embedded electrical power system were presented. The power system is composed of one Li-Ion battery directly connected to the dc bus (in the first case) or by means of a boost converter (in the second case) and a supercapacitor energy storage device that is connected to the DC-link by using a bidirectional buck–boost converter. These two structures were simulated using Matlab/Simulink environment. The second configuration gives better results since the battery discharge is controlled by means of a fuzzy-logic supervisor.

Acknowledgment. This paper was supported by the project "Development and Support of Multidisciplinary Postdoctoral Programmes in Major Technical Areas of National Strategy of Research – Development – Innovation" 4D-POSTDOC, contract no. POSDRU/89/1.5/S/52603, project co-funded by the European Social Fund through Sectoral Operational Programme Human Resources Development 2007-2013.

REFERENCES

Chen T.L., Pan P.L., *The Research of Smart Li-Ion Battery Management System*. Proc. 2nd IEEE Conf. Ind. Electron. Appl., Harbin, China, May 23–25, 2007, 2273-2277.

Vazquez S. *et al.*, *Energy Storage Systems for Transport and Grid Applications*. IEEE Trans. Ind. Electron., **57**, *12*, 3881-3895 (2010).

Zhang H., Saudemont C., Robyns B., Petit M., *Electrical Features Comparison Between More-Electric Aircrafts and Hybrid Electric Vehicles*. Electromotion, **16**, *3*, 111-119 (2009).

SISTEM HIBRID DE STOCARE A ENERGIEI PENTRU ECHIPAMENTE ELECTRICE ÎMBARCATE PE VEHICULE

(Rezumat)

Sistemele electrice îmbarcate pe vehicule se dezvoltă într-un ritm alert datorită introducerii avansate a tracțiunii electrice în sectorul transporturilor. Vehiculele electrice, hibride-electrice, trenurile de mare viteză şi avioanele au un numitor comun – sistemele electrice îmbarcate. Lucrarea îşi propune să prezinte comparativ două configurații ale unui astfel de sistem, primul cu o structură mai simplă, iar cel de-al doilea, încorporând o metodă de supervizare utilizând logica fuzzy. Rezultatele obținute prin simulări numerice demonstrează avantajele acestui tip de supervizor.