# BULLETIN OF THE TRANSILVANIA UNIVERSITY OF BRAŞOV

TRANSILVANIA UNIVERSITY OF BRAŞOV

Vol. 1(50), 2008
ISSN 2065-2127

## SERIES I
## ENGINEERING SCIENCES

Published by Transilvania University Press
Braşov, Romania, 2008

# CONTENT

## • MECHANICAL ENGINEERING



## • INDUSTRIAL ENGINEERING

## • MATERIALS SCIENCE AND ENGINEERING

## • ELECTRICAL ENGINEERING, ELECTRONICS AND AUTOMATICS

## • CIVIL ENGINEERING

# IMPROVING THE ENERGY MANAGEMENT FOR LDH-1250HP LOCOMOTIVE USING EMBEDDED SYSTEMS

**M.C. CARP[1] D. SOJERF[2] P.N. BORZA[1]**
**Gh. TOACŞE[1] A.M. PUŞCAŞ[1]**

***Abstract:*** *The paper presents the implementation of a new energy management system on LDH 1250HP locomotives and the prototype realized by upgrading and improving the existing old fashioned voltage regulator and the starting system of the locomotive. The models considered, the developed topology as well as the chosen strategy in the energy management is described in this article. The approach for this challenge consists in an embedded system, a set of intelligent sensors, and high power switching in order to accomplish an optimal energy transfer from super capacitors and lead-acid batteries, to the DC starting motor of ICE. The solution implemented by us reduces the number of lead-acid batteries at half of initial and increases the batteries' life time.*

***Key words:*** *adaptive control, embedded system, topology, energy management, super capacitors.*

## 1. Introduction

The demographic evolution, the important changes on the economical plan, on the climate plan, the reduction of the energetic resources likeness fossil deposits, impose to develop an optimal energy management which can maintain the highest standards of human society requests.

Our target through this energy management is to reduce the quantity of the fuel consumption and of course the pollution grade caused by the usage of the shunting locomotives as LDH1250HP [1].

Thus, within the framework of this energy management we follow to improve the locomotive's starting system and concomitantly to correctly administrate the charging of the lead acid (L-A) batteries.

The current evolution in the nano-technologies domain has lead to new material structure achievement able to fulfil the requirements from the point of energy and power density offered by electric storage devices such as super capacitors [2].

Because a single device is unable to satisfy all the requirements of the applications the natural development of such an application leads to the idea of using a combination with power electronics of several devices such as super capacitors and L-A batteries for the implementation of the storage devices with flat response in time.

These solutions give us the optimum

[1] Dept. of Electronics & Computers, *Transilvania* University of Braşov.
[2] Werkstoffe Technologien Transfer Consulting, Berlin, Rudower Chaussee 29 D-12489.

compromise in respect of the equipments cost, size and system maintenance.

In order to choose the optimal storage solution for the electrical energy the following storage medium has been considered in our study (see Figure 1).

| | Power rating | Discharge duration | Response time | Efficiency | Lifetime | Maturity |
|---|---|---|---|---|---|---|
| **Pumped hydro** | 100 – 4000MW | 4 – 12 h | sec – min | 0.7 – 0.85 | 30 y | commercial |
| **CAES (in reservoirs)** | 100 – 300MW | 6 – 20 h | sec – min | 0.64 | 30 y | commercial |
| **CAES (in vessels)** | 50 – 100MW | 1 – 4 h | sec – min | 0.57 | 30 y | concept |
| **Flywheels (low speed)** | < 1650 kW | 3 – 120 s | < 1 cycle | 0.9 | 20 y | commercial products |
| **Flywheels (high speed)** | < 750 kW | < 1 h | < 1 cycle | 0.93 | 20 y | prototypes in testing |
| **Super-capacitors** | < 100 kW | < 1 m | < 1/4 cycle | 0.95 | 500,000 cycles | some commercial products |
| **Lead-acid battery** | < 50MW | 1 m – 8 h | < 1/4 cycle | 0.85 | 5 – 10 y | commercial |
| **NaS battery** | < 10MW | < 8 h | n/a | 0.75 – 0.86 | 5 y | in development |
| **Hydrogen (Fuel Cell)** | < 250 kW** | as needed | < 1/4 cycle | 0.34 – 0.40* | 10 – 20 y | in test |
| **Hydrogen (Engine)** | < 2MW** | as needed | seconds | 0.29 – 0.33* | 10 – 20 y | available for demonstration |

*AC-AC efficiency

** Discharge device. An independent charging device (electrolyser) is required

Fig. 1. *Comparison between different kind of storage devices* [9]

Related to the power and energy density we have presented the Ragone diagram Figure 2.

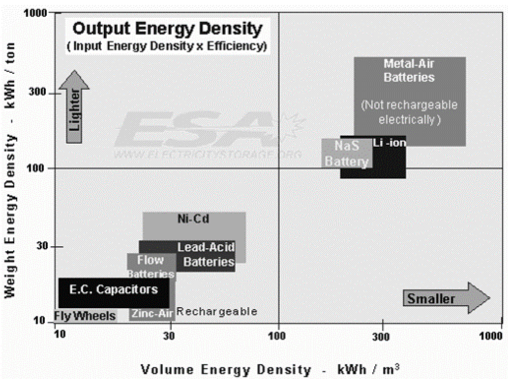


Fig. 2. *Ragone diagram for different kind of storage devices and their features* [9]

The analysis made so far emphasis the fact that super capacitors have an efficient power consistence and an increase life time reported to other storage medium [3].

The result of the study is presented in Figure 3.

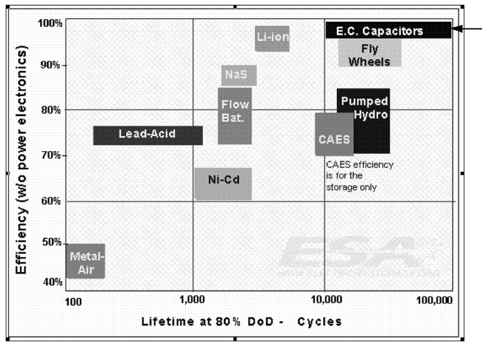


Fig. 3. *Efficiency& Lifetime at 80% DoD for each technology* [6]

Because we had to choose an optimal storage medium, the following features are very meaningful and were evaluated:

- A high power capacity,
- A high power density,
- A very quick charging time (in order to do the super capacitor’s charging it is no need for special circuits),
- There is no possibility for overload,
- Cycle life time very high, more than 500.000,

- No chemical actions or environmental damages,
- A very low output impedance less than 20 mΩ.

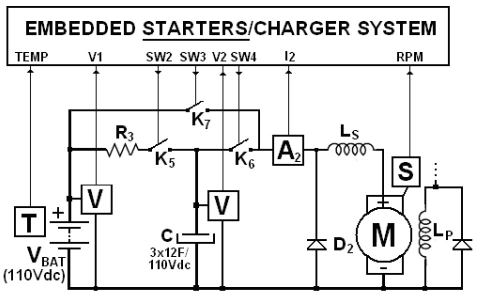


Fig. 4. *The hardware block diagram of starter system's management*

- A very large temperature range: –40 ºC to +85 ºC.

## 2. System's Description

The system storage for electrical energy necessary to the starting system includes one battery of $8^{th}$ series lead acid batteries which provides a capacity of 150 Ah at 110 V (this storage capacity represents half of the initial one (360 Ah at 110 V)). We have used one group of three capacitors, each at 12 F/110 V connected in parallel that means 36 F at 110 V.

The technology development for these super capacitors is the Electric Double Layer Capacitors (EDLC) type with aqueous electrolyte each of them with 20 mΩ Equivalent Series Resistance (ESR). As features, the temperature range is between –40 ºC to +85 ºC weight 40 Kg, size 23 cm diameter and length 42 cm. The stored energy on each is about 72 KJ.

For this super capacitors battery's charging process we have used two in parallel power MOS transistor, each at 82 A @ 150 V.

For its discharging on DC series motor we have used a 4000 A/1200 V SCR thyristor from EUPEC.

## 3. System's Hardware

The hardware structure of the control system includes three sub-systems: the starting system of ICE supplied from locomotive's batteries, and two other sub-systems mounted in cascade: first used for voltage regulator and short circuit protection, that supplies the ancillary loads on locomotive and the second, used to optimally charge the batteries [4]. The first sub-system is presented in Figure 4. The starting sub-system as reaction at locomotive driver, will initiate a sequence of commands that will be described in the "software developments" paragraph.

The key components of the system are [16]:

**$K_1$, $K_4$, $K_5$** - HEXFET Power MOSFET (IRFB4321) 83A/150V [4];

**$K_2$, $K_6$** - IGBT (CM600HA) 600 A/ 1200 V [12];

**$K_3$** - IGBT (IRG4PC40FD) 27 A/600 V [8];

**$K_7$** - Thyristor (TBS702350) 4000 A/ 1200 V [7], [15];

**$A_1$** - Hall Current Transducer LTSR 25-NP 25A [10];

**$A_2$** - Open Loop Hall Effect Current Sensor (CYHCT-C1-1500A-22) 1500A [5];

**V** - Voltage Transducer (LV25-P) 10-500 V [11];

**C** - Super capacitor 3 x 12 F/110 Vdc;

**$V_{BAT}$** - Lead-acid batteries 8 x 12 V/150 Ah;

**T** - LM35 Precision Centigrade Temperature Sensor [13];

**S** - Rotational speed sensor KMI15/4 [14];

**Ls** - serial coil motor inductor;

**Lp** - parallel coil motor inductor.

The other sub-systems will implement the voltage regulator on the locomotive. The third one will be used for charging the group of batteries (Figure 5).

For the third sub-system we have used the voltage relaxation method to measure the State of Charge (SoC) of the batteries [15].

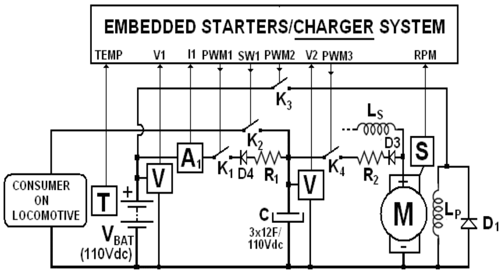


Fig. 5. *The hardware block diagram of charger system's management*

In accordance with this method we have in advance determined the characteristics of the batteries, function of the Integral Charge, temperature, self discharge characteristic and EMF - Electro Motive Force (see relaxation voltage method). The microcontroller system will take into account these characteristics as Look Up Tables (LUT).

## 4. System's Software

In order to optimally control the starting and the charging processes we have developed an embedded software. The flow diagram of its it is presented in Figure 6.

The starting system will implement a starting sequence that supposes the following steps:

- charging the super-capacitor from batteries before starting;
- at the driver locomotive initiative switch on the thyristor ($K_5$) that will discharge the super capacitor on DC starting motor;
- monitors the voltage/current variation into the circuit and detects by software the moment of switching on the IGBT ($K_7$) that will apply the batteries' voltage on the DC starting motor. As result of this last action the thyristor will be look;
- the rotation speed sensor will indicate to the system the moment when the IGBT will be switch off as a result of ICE start.

The experimental results prove that the starting process was reduced at maximum 4.5 s, mainly this result is determined by the existing mechanical rotation speed regulator (based on oil pressure) that need minimum 3 seconds to reach the necessary pressure.

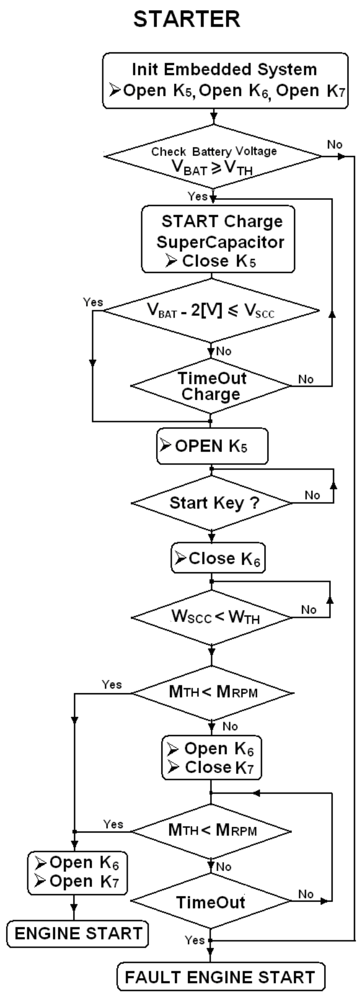


Fig. 6. *The software block diagram of starter system's management*

$V_{SCC}$ - super capacitor voltage,

$W_{SCC}$ - current energy stored on the super capacitor,

$W_{TH}$ - minimum of energy stored on the super capacitor to switch on battery,

$M_{TH}$ - minimum of crankshaft speed, in revolutions/minute, for start ICE,

$M_{RPM}$ - current crankshaft speed, in revolutions/minute,

C - battery capacity [Ah],

$V_{NOM}$ - nominal voltage,
$I_{NOM}$ - nominal current,
$V_{BAT}$ - battery voltage,
$V_{TH}$ - minimum of battery voltage to start ICE.

The implemented algorithm assures the minimum necessary time to reach the settled voltage on super capacitors, also avoiding the over current on generator (Figure 7).

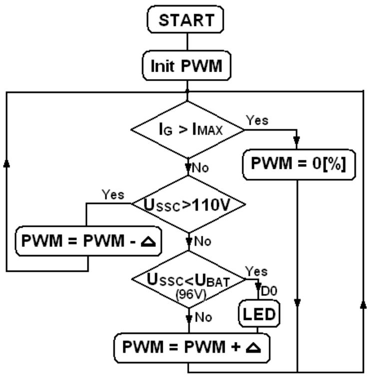


Fig. 7. *The software block diagram of super capacitor charger system's management*

## 5. Implementation and Experimental Results

As it is shown in Figure 8 the "ralenti" rotation speed is reached in less than 200 ms and after that we can observe each stoke that appears in the cylinders of ICE.

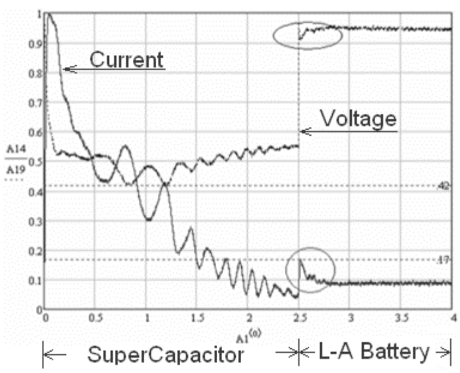


Fig. 8. *Current and voltage variation for the LDH1250 with the new energy management system*

By experiments we establish ten numbers of successive explosions that will assure the optimal moment when we will switch on circuit the batteries in order to realize a reliable regime for ICE.

## 6. Conclusions

As we have presented in the present article, the use of the super capacitors became mandatory if we think at implementing a non polluting system able to efficiently manage the starting process of the diesel locomotive.

Advantages of the management of engine's start with super capacitors are:

- Can assure a reliable starting process of the ICE in a large range of temperature from −30 ºC to +80 ºC because the transfer for short term of power to the DC starting engine is assured in quite similar electrical condition by the super capacitors controlled by our new energy management system.
- As functionality, the efficiency of the electrical accumulators (for the nominal currents) is about 70% [3]; this value is much lower for greater currents (at the starting process) while super capacitors have much greater efficiency (about 90%, due to very low internal resistance). As a direct result of this fact the energy consumption it is decreased as well.
- The starting process becomes more rapid by using super capacitors because it can deliver a greater power density.
- By using super capacitors and a monitoring and controlling embedded system, the life-span of the battery is extended thus avoiding battery's over-voltage.
- Because the starting process is made from the super capacitor, the battery is protected and multiple deep discharges (caused by multiple starts) are avoided; thus, the battery's life time is extended.
- Using the super capacitors as temporary

buffer of energy provided by generator on locomotive allows us to use a very precise algorithm for the charging system of the batteries integrated into the energy management system.

- The reliability and also the availability of the whole locomotive is increased as a result of a better functioning conditions assured by the batteries. More that, we have demonstrated by testing the prototype that the size of the batteries for the same locomotive was reduced at more than the half of initial ones.
- Because we have developed a firmware in order to control the locomotive and to switch off the engine for any dead time of the locomotive's ICE, the fuel consumption is reduced; the embedded system's firmware designed by us was implemented in order to assure a the very high availability of the new starting system;
- As a future work, new possibilities related to the optimization of the functionality and also the energy efficiency of vehicles has to be made by integrating all the electrical services under the same control system.

## References


1. Borza, P., Carp, M., Puşcaş A.M., Szekely, I., Nicolae, G.: *Energy Management System Based on Supercapacitors Used for Starting of Internal Combustion Engines of LDH1250 Locomotives and Charging Their Batteries.* In: International Symposium for Design and Technology of Electronic Packages, SIITME, Predeal, România, 2008, p. 227-231.
2. Pop, V.: *Battery Management Systems Accurate State-of-Charge Indication for Battery-Powered Applications.* Springer Science + Business Media B.V., 2008.
3. Stanca, C., Sandu, F.: *Microcontroller-based Management System of Supercapacitor-aided Vehicle Starter.* In**:** International Symposium for Design and Technology of Electronic Packages, SIITME, Predeal, România, 2008, p. 115-119.
4. Tomuța, O., Rogoveanu, N., Iliescu, P.: *Acumulatoare pentru autovehicule.* Bucureşti. Editura Tehnică, 1990.
5. http://www.bbautomacao.com/pdfs/CYHCT-E4B.pdf.
6. http://www.electricitystorage.org/tech/technologies_comparisons_lifeefficiency.htm
7. http://www.irf.com/product-info/datasheets/data/irfb4321pbf.pdf.
8. http://www.irf.com/product-info/datasheets/data/irg4pc40fd.pdf.
9. http://www.iwea.com/index.cfm/page/archive?rdDF=2007%2011%20Energy%20Storage%20Techniques.pdf.
10. http://www.lem.com/docs/products/LTSR%2025-NP%20E.pdf.
11. http://www.lem.com/docs/products/LV%2025-500%20E.pdf.
12. http://www.mitsubishichips.com/Global/content/product/power/powermod/igbtmod/tgatef/cm600ha-5f_e.pdf.
13. http://www.national.com/ds/LM/LM35.pdf.
14. http://www.nxp.com/acrobat_download/datasheets/KMI15_4_4.pdf.
15. http://www.pwrx.com/pwrx/docs/tbs7--35.pdf.
16. *** Project "TRANS-SUPERCAP", PNII-P4, 2007, 21-018/14.09.2007.