INTELLIGENT CONTROL SYSTEM USED FOR INCREASING THE ENERGY EFFICIENCY OF THE ELECTRIC VEHICLES - REDUCED SCALE MODEL -

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ABSTRACT - The actual constraints related to the air pollution, fuel and energy consumption became essential aspects considered while improving the performances of the classic vehicles and developing the new generation of mild hybrid electric vehicles and electric vehicles. Also, assuring the dynamism of the vehicle became an important goal that need to be assessed by the automotive industry. Nowadays, one of the main focuses of the automotive researchers is developing innovative power supplies and composed storage devices able to assure the dynamism of the vehicles thus facilitating the transition from the classic internal combustion engine (ICE) vehicles to the new generation of mild hybrid electric vehicles (HEV) and electric vehicles (EV). A solution for the actual constraints can be a combined energy and power supply system composed of storage devices characterized by different time constants. The present paper is focused on describing a physical reduced scale prototype of an electric vehicle and its control strategies able to satisfy better the requirements for increasing the energy efficiency of the implemented and tested system. In this paper the role of the used storage devices and of the control strategies are emphasized. Also, the architecture of the system, the experiments performed and the preliminary results are described.

INTRODUCTION

Generally, batteries are used as main power supply, especially for EV, but their cyclability and functional constraints related to the current provided and the operating range of temperature are improving slowly compared to the consumer's requests because of the high cost of the technology. Lately, new storage devices such as fuel cells and capacitors / supercapacitors are used by the automotive industry to increase the energy efficiency and the storage and generating capabilities, constraints that have to be assessed in the case of the new generation of HEV and EV (1).

A solution for the actual constraints can be represented by a combined energy and power supply system composed of devices with different time constants, such as: batteries, supercapacitors, fuel cells and their intelligent control system able to optimize the power flow of the electric engine, to monitor and to increase the lifetime and the performances of the ensemble (2), (3). The capabilities and the power flow reserves of the energy sources increase the dynamicity of the vehicles. Moreover, the role of the regenerative braking in conjunction with the rapid release storage devices is essential for urban traffic in order to increase the energy efficiency of the ensemble (4).

In the present paper a physical reduced scale prototype of an EV is described. The prototype is intelligently started and is able to recover a part of the kinetic energy from the braking process, to store it in capacitors and to use it to supply the auxiliary loads. The role of the capacitors and of the implemented and tested control strategies able to satisfy better the requirements of the starting and regenerative braking processes are emphasized. Also, the structure of the system, the experiments performed and the preliminary results are described.

The *aim* of the research is optimizing the energy consumption of the EV and increasing their dynamicity by using embedded systems based on microcontrollers and switching devices. The *goal* of the paper is to implement a physical reduced scale prototype thus offering a better understanding of the influence factors considered while designing and sizing the composed storage devices, their command and their control strategies in order to assure high reliability and increased energy efficiency for the transport missions.

STATE OF THE ART AND EXISTING PROBLEMS

Lately, reducing the fuel, energy consumption and the pollutant emissions became a real challenge for automotive researchers which focused their studies toward improvements for HEV and EV. The biggest problem is ensuring the requirements for the urban traffic which has an increased number of the braking / acceleration (starts, stops and regenerative braking). Unfortunately, during the starting process, the vehicle requires a spike of current which drastically affects the performances and the lifetime of the battery, this problem being more important while considering the batteries used in electric vehicles as main power sources (5).

START / STOP AND REGENERATIVE BRAKING SYSTEMS

Start/Stop system represents a system able to automatically stop the engine when the vehicle is stationary and also able to automatically start de engine when it identifies a sequence of commands.

For urban driving, new researches demonstrated that the fuel consumption can be reduced until 2012 with up to 0.2 l /100 km and the pollutant CO_2 emissions with up to 5 g / km by the Start/Stop system (6), (7), (8), (9), (10). In 2009 Audi developed an efficient modular Start/Stop and regenerative braking platform with On-Board Computer for reducing the fuel consumption with up to 20 % (6). Researchers from Citroen were also focused on efficiently implementing the Start/Stop system (8), (9). For increasing the temperature range of operation, there are studies which correlate the automatic Start/Stop processes with the temperature of the engine (7).

Moreover, the energy from the braking process can be partially recovered by using a special system, adequate storage devices and control strategies. Audi and Citroen implemented on their vehicles regenerative braking systems (6), (8). The energy recovered in the deceleration phase was used in the acceleration one in order to increase the performances of the concept vehicles and to reduce the energy consumption. Valeo Start/Stop StARS + X system uses both Start/Stop and regenerative braking to achieve better performances in the process of reducing with up to 25 % the energy and fuel consumption in urban traffic (11).

Even if in present there are special systems used for the battery protection, the repeated Start/Stop processes reduce the lifetime of the battery and also, the medium time constant of the battery reduce the efficiency of the energy recovering system. Therefore, it has to be made a compromise between increasing the energy efficiency and reducing the lifetime of the battery. Thus, this field still represents a thematic of scientific interest and there are researches focused on developing composed storage devices with increased lifetime.

COMBINED STORAGE DEVICES

In order to increase the lifetime of the battery, a composed battery-supercapacitor energy storage and generation system can be implemented and used. The supercapacitors have the advantage of being non-polluting storage devices with long lifecycle, high power density and increased mechanic resistance. Researchers (12) developed a hybrid battery-supercapacitor system proper for light vehicles and low speed (25-31 km / h). The experimental results proved that such hybrid devices considerably reduce the mechanic stress of the battery without drastically reducing their performances.

Our goal is to implement an intelligently controlled combined energy storage device (CESD) used in the starting and regenerative braking processes of the reduced scale EV prototype.

THE ARCHITECTURE OF THE IMPLEMENTED SYSTEM

The CESD was used in the starting and regenerative braking processes. In the starting process a capacitor as energetic buffer was used to supply the peak current required, thus protecting and resizing the battery. In the regenerative braking process, capacitors were used to store the recovered energy from the braking thus increasing the energy efficiency of the prototype. Capacitors were used in the starting and regenerative braking processes because of their advantages related to the possibility of supplying high peak current pulses without their performances being deteriorated, their reduced time constants and their long life cycle.

The developed embedded control system together with the sensor network are characterized by their availability and are endowed with intelligence to optimally monitor, manage and control the storage and generation devices, the switching devices and the auxiliary loads of the prototype. Such a scalable and reliable system represents an important key for improving the energy efficiency of the EV and for increasing the lifetime of the batteries used in the supplying process.

The implemented system (Fig. 1) has two main functions: (i) is an efficient Start/Stop system, starting the prototype from the capacitor in order to increase the lifetime of the battery; (ii) it recovers the energy from the braking process.

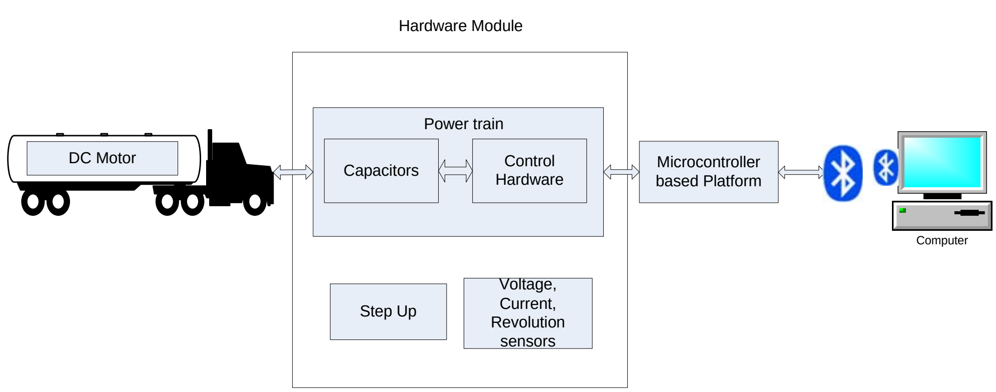

Fig. 1 Architecture of the implemented system

As it can be seen in Fig. 1, the architecture of the system is divided in 4 main modules: the reduced scale EV, the Hardware Module, the Microcontroller based Platform and the Data Acquisition System (DAQ - Computer). The Hardware Module consists in (i) Power train composed of energy storage devices, switches, (ii) Step Up module for amplifying the voltage in the regenerative braking and (iii) sensors for monitoring the value of the voltage, current and revolution. Data acquired by the Microcontroller based Platform are stored, interpreted and wirelessly transmitted to a computer where decisions are taken.

To increase its efficiency, controllability, availability and to facilitate its maintenance, the system was modular implemented. To wirelessly control the system from the laptop, an adapter between RS232 and Bluetooth was also implemented.

STORAGE DEVICES

The system was supplied from 3 storage devices: 1 pack of secondary batteries and 2 22.000 µF / 25 V capacitors (Fig. 5). One of the capacitors ("*capacitor 1*") together with the pack of batteries were used by the Start/Stop system to provide and also to smooth the spikes of current which appear in the starting process and reduce the lifetime of the battery. Because of its reduced time constants, the second capacitor ("*capacitor 2*") was used for storing the energy recovered during braking and also for supplying the auxiliary loads of the vehicle (e.g. lights). The combined battery-capacitor storage device not only increases the lifetime of the battery but also, it can reduce the size of the batteries used in the supplying process.

To demonstrate the benefits of using a composed battery-capacitor storage device, the following configurations (Fig. 2 a, b) were simulated.

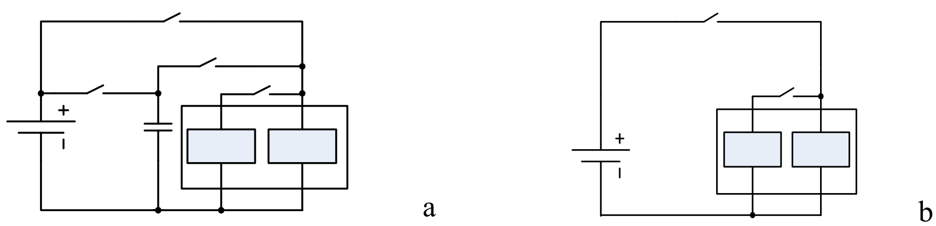

Fig. 2 a. Composed battery-capacitor device for Start/Stop process
b. Typical configuration used for Start/Stop

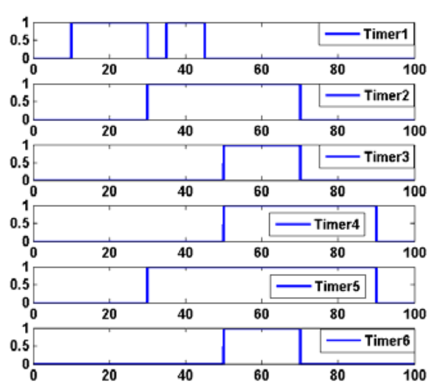

Fig. 3 Switches commands

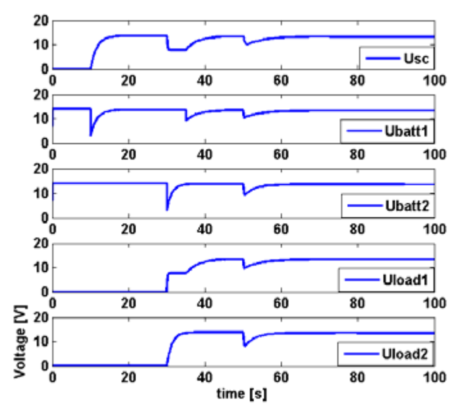

Fig. 4 Results of the simulation

In simulations, the commands (T1-T6) illustrated in Fig. 3 were used to activate the switches. The results of the simulations are illustrated in Fig. 4.

As it can be seen in Fig. 4, the hybrid battery-capacitor configuration (Fig. 2 a) can provide the load profile in a shorter period than in the case of supplying the load from the typical configuration (Fig. 2 b) used in present on vehicles.

HARDWARE ARCHITECTURE

In order to protect and to increase the lifetime of the capacitors and of the pack of the batteries, the voltage of the storage devices was permanently monitored and interpreted. The configuration of the implemented power train is illustrated in Fig. 5 and the implemented reduced scale EV prototype in Fig. 6.

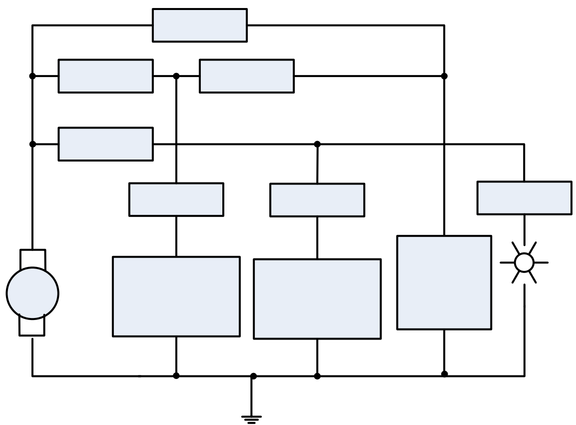

Fig. 5 Architecture Of The Power Train

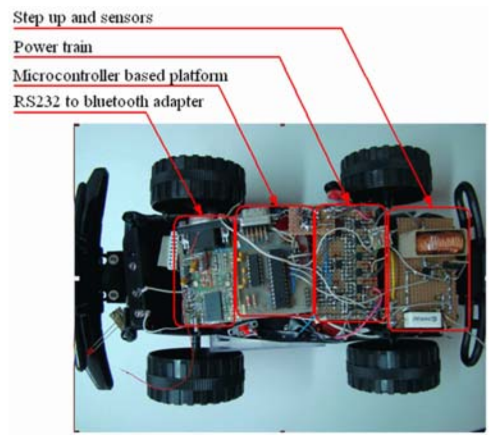

Fig. 6 The reduced scale prototype

SOFTWARE ARCHITECTURE

Based on the acquired data, the command and control software implemented in ICCAVR tool had the ability to avoid the overcharge and deep discharge phenomena and also had to ensure the energetic profile of the load. One of the implemented algorithms for controlling the system is illustrated in Fig. 7.

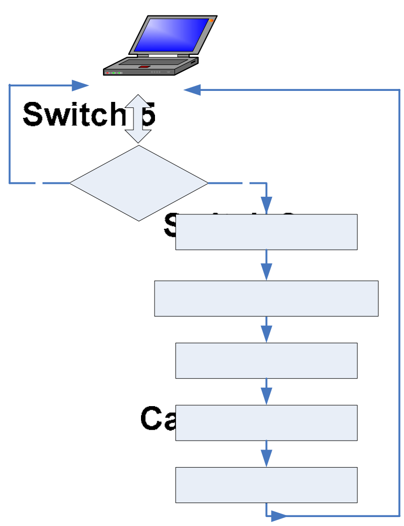

Fig. 7 Implemented testing algorithm

EXPERIMENTAL RESULTS

The implemented algorithm tested the functionality of the starting and regenerative braking processes. In the starting process, the load was firstly supplied from the "*capacitor 1*" and after that the energy was provided by the battery. The regenerative barking tested the efficiency of recovering the kinetic energy from braking and storing it into "*capacitor 2*".

The experimental results are illustrated in Fig. 8 - Fig. 11. The experimental data were acquired with 31 samples / second and the revolution was determined at each 10 ms.

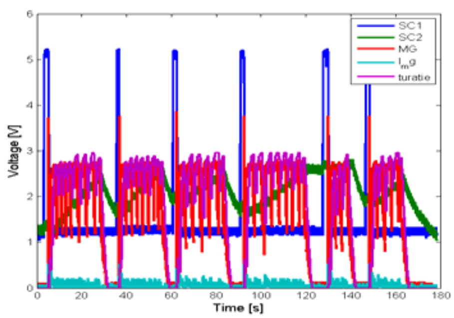

Fig. 8 Experiment 1

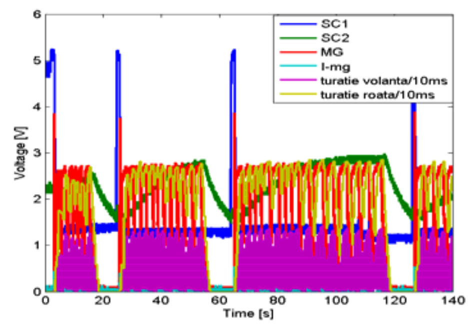

Fig. 9 Experiment 2

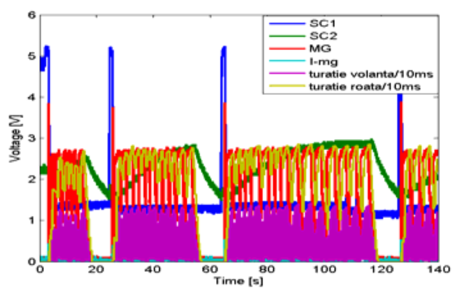

Fig. 10 Experiment 3

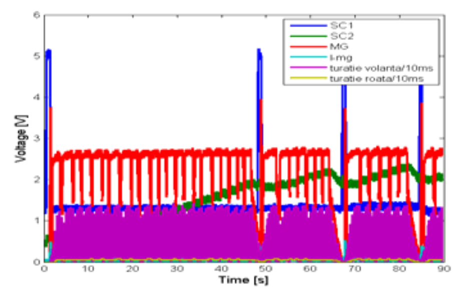

Fig. 11 Experiment 4

As it can be seen in Fig. 8 - Fig. 11, the "*capacitor 1*" is charged before the starting process at the nominal voltage of the pack of batteries in order to provide the current required by the system in the first milliseconds thus protecting the battery and reducing the energy consumption. After the voltage of the "*capacitor 1*" decreases at the minim voltage threshold, the load is supplied from the other pack of batteries.

Also, the energy recovered during braking and stored in "*capacitor2*" can successfully supply the auxiliary load of the vehicle (in this case the lights). As it can be seen, the lights are supplied from the recovered energy for about 20 s, fact which is satisfactory if taking in consideration that usually this energy is wasted into heat.

THE ENERGY FLOW

Based on the experimental results the energy efficiency was determined. The diameter of the wheel is d_R = 7.2 cm, the distance made during one revolution is $l_R = \pi \cdot d = 0.226$ m and the transmission ratio of the prototype is $\frac{d_v}{d_R} = 18$.

The conversion between revolution (n) and angular speed (ω) is $n = \frac{60 \cdot \omega}{2 \cdot \pi}$.

The linear speed can be expressed as it follows: $v = 2 \cdot \pi \cdot r \cdot \frac{1m}{100cm} \cdot RPM \cdot \frac{1\min}{60\sec}$.

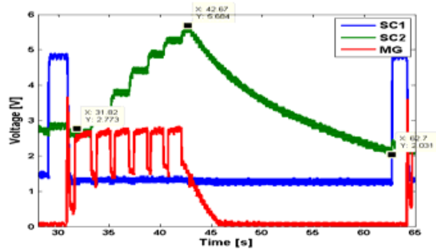

Fig. 12 Experiment 5 – supplying the lights with the energy recovered during braking

The experimental results illustrated in Fig. 12 were used to determine the efficiency of the regenerative braking process. In the first analyzed case, 6 stages of 1.3 s acceleration were alternate with 5 stages of 0.5 s braking. During this process the voltage on the *capacitor 2* was increased with 3 V and the resulted energy was used to supply the lights of the vehicle during 20 s.

The energy recovered during one braking is: $E_c = \frac{m \cdot v^2}{2} = \frac{0.6 \cdot 1.4^2}{2} = 0.588J$. In the experiment illustrated in Fig. 12, there were 5 brakings before supplying the lights from the "*capacitor 2*": $E_{capacitor2} = \frac{C \cdot (U_{\max}{}^2 - U_{\min}{}^2)}{2} = \frac{22.000 \cdot 10^{-6} \cdot (5.684^2 - 2.031^2)}{2} = 0.31J$.

In this example, the global efficiency of the energy recovered during braking and used for supplying the lights is: $\eta = \frac{E_{capacitor2}}{E_c} = \frac{0.31}{5 \cdot 0.588} = 10.54\%$.

Usually, in the braking process, the kinetic energy is wasted into heat. Such a regenerative braking system can consistently reduce the energy consumption, can improve the energy efficiency and can increase the lifetime of the main power devices - the battery.

CONCLUSIONS

Increasing the energy efficiency of the vehicles became an important goal of the automotive researchers, the trend being to implement the Start/Stop and regenerative braking systems as standards in vehicles.

The paper emphasized how a Start/Stop system can be efficiently implemented, the role of the storage devices used in present in automotive and the possibilities for recovering the kinetic energy in the braking periods. Both of the processes were monitored and controlled by intelligent strategies.

A combined battery-capacitor storage device was described and simulated. Its advantages related to smoothing the high peak currents and reducing the necessary time for supplying the load were demonstrated. Such a system can increase the lifetime of the battery and can resize the battery used in the starting process Based on the experimental results and on the determinations it was demonstrated that the energy efficiency of the vehicle was increased.

The physical reduced scale EV prototype represents a useful way for understanding the energy flow, the energy conversion and the influence factors considered while designing and sizing the composed storage devices, their command and their control strategies in order to increase energy efficiency in vehicles. Combining these phenomena with intelligent control strategies, energy efficiency can be increased.

As future work, a real scale prototype has to be implemented and the energy efficiency of the regenerative braking process has to be increased. To improve the energy efficiency, supercapacitors will be used, the most important advantages of supercapacitors being the high power density in a reduced volume, their long life cycle and their capabilities of supplying high peak current pulses without having their performances reduced.

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