EXPERIMENTAL VEHICLE FOR RESEARCH ON THE ELECTRIC PROPULSION SYSTEMS ENERGY MANAGEMENT

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Abstract: This paper presents an experimental vehicle that was realized for testing the electric propulsion system and for research concerning the system energy management. There are presented the vehicle structure, its functionality and a special built monitoring system. The monitoring system is able to on-line display the specific quantities during tests and to automatically build a measurement data base for various operating conditions, which is meant to be used for research on energy management optimization.

Keywords: vehicle monitoring, electric vehicle, electric drives.

1. INTRODUCTION

A good correlation of the functional parameters involved in a vehicle electric drive is a point to be considered in order to obtain high efficiency traction. Since the tests of the vehicle propulsion systems in real operating conditions can offer valuable information about its behavior and also can reveal possibilities of improvements, an experimental vehicle was built by the authors. It includes a car body, a traction battery pack, an electric drive, switching and protection devices, electronic interface for operator commands and a monitoring system.

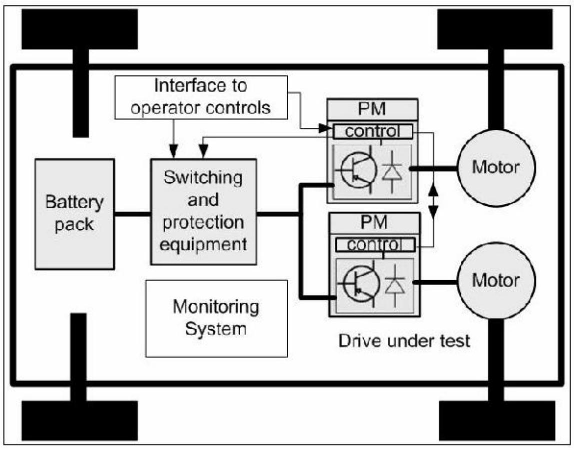

Fig. 1. The structure of the experimental vehicle

At this time the experimental vehicle is equipped with an electric drive having two independently controlled Brushless DC (BLDC) motors. The motors are especially designed for traction, and equipped with Hall sensors.

The schematic diagram of the experimental vehicle is presented in figure 1.

Each motor is separately controlled by its own power module, and the torque command is given by the user through a pedal position transducer linked to the acceleration cable of the original classic vehicle.

2. THE MECHANICAL STRUCTURE

In this two-motor drive system, the maximum dimensions of the motors that can be tested are imposed by the distance between wheels (considering also the semi-axles length) and the ground clearance. Thus the maximum motor diameter is 300 mm, and the maximum motor length is 135 mm, as illustrated in fig. 2.

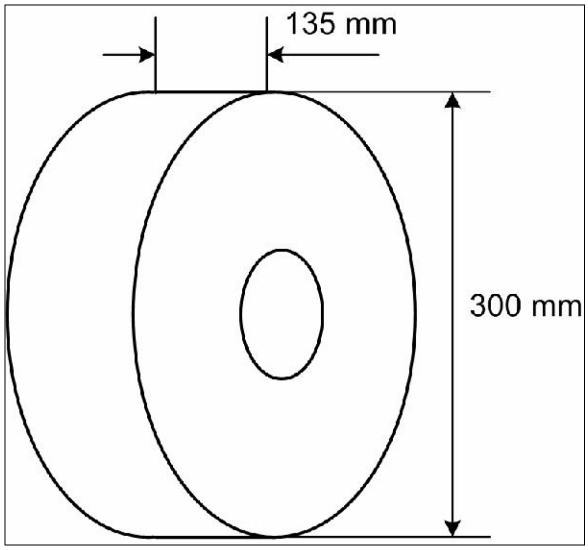

Fig. 2. The maximum dimensions of the motors that can be tested on the platform

As a supporting mobile structure it was chosen a small vehicle, in order lower the electric consumption and costs of the test equipment. Both electric motors were fixed in the motor compartment, as shown in figure 3.

Fig. 3. The independent two-wheel drive fixed in the motor compartment

There were built two motor supporting structures which are immovable relative to the chassis, which allowed coupling the motors to the wheels using the semi-axles of the classic vehicle, as shown in figure 4.

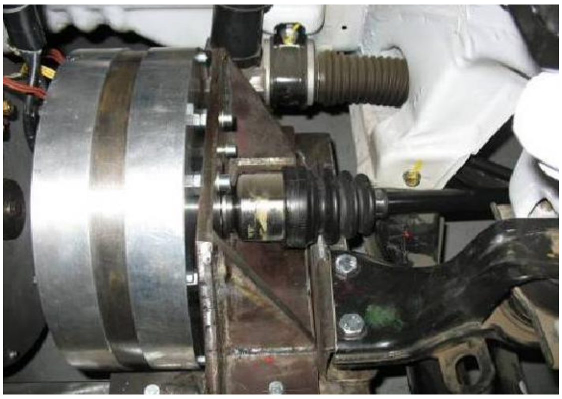

Fig. 4. The left side motor fixed attached to the semi-axle

3. THE POWER SOURCE AND THE SWITCHING AND PROTECTION DEVICES

The power source consists in ten Lead-acid Batteries – GB 12-100 type, BSB Power, 12 V and 100 Ah capacity, connected in series. The battery package is put in two rows, in the back half of the vehicle, as shown in figure 5.

The maximum DC voltage and current provided by the batteries are 12x10 V and 100 A respectively, having a capacity of 100 Ah. These values altogether were imposed by the vehicle dimensions and its maximum load weight.

The battery feeds the power modules through a fault protection circuit including fuses, a circuit breaker and a contactor. The vehicle drive scheme is illustrated figure 6. Besides the over current protection, the circuit breaker is used to manually

Fig. 5. The battery package and the power modules

disconnect the source when the equipment is not utilized. The contactor is switched by the contact key, as also shown in figure 6.

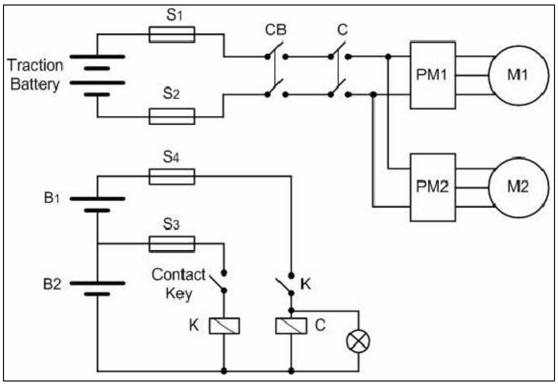

Fig. 6. The vehicle drive scheme

4. THE POWER MODULES AND MOTOR CONTROL

Each power module consists in two main parts:

- the power part – basically a three-phase bridge inverter, with pulse-width-modulation (PWM) driven IGBTs;
- the control part, which is implemented on a dedicated motion control board - Technosoft MSK2407 [6], built around the fixed point Texas Instruments TMS320LF2407 Digital Signal Controller.

The board is software programmable using a high-level motion language [7] and the IPM Motion Studio software package, both created by Technosoft. This package running on a PC, allows connection between PC and the controller board, setup configuration, the controllers tuning etc. The program is downloaded from PC through RS-232 interface.

The primal software component of the control part is the real time motor control kernel, as part of the firmware already supplied with the board. There are several motor control techniques which can be easy chosen and configured using the graphical user interface: sensored (encoder) and sensorless vector control for sinusoidal permanent magnet motors (PMSM), or trapezoidal control for Brushless DC Motors using Hall sensors.

The software is especially designed for multiple axis control - the power modules are connected in a network using CAN (Controller Area Network) bus for communication. In the present configuration of the vehicle drive system, one power module, the master, receives the torque command through an analog input, and transmits it to the slave power module by the CAN bus.

The distinctive feature of the entire drive system control is the modality chosen for the supervisor implementation. This is not a separate entity, but it is included in the master power module (PM1), at software level. The solution is economical and practical, as the controller board has sufficient processing and memory resources so that additional higher level tasks are supported: battery management, critical events counting and signaling.

5. THE MONITORING SYSTEM

The specific motor and drives quantities can be viewed and acquired during the tests using a monitoring system, created for this purpose.

It is a PC-aided monitoring system, which was considered to be very well suited for this application – which requires a large number of channels and a large amount of data to be stored. The features and the hardware and software parts of the monitoring system are presented in the following subsections.

A. The Hardware Part

The hardware structure of the monitoring system, presented in figure 7, comprises the voltage and current transducers, the signal conditioning modules and a modular data acquisition system, which is connected to a laptop PC through a USB port.

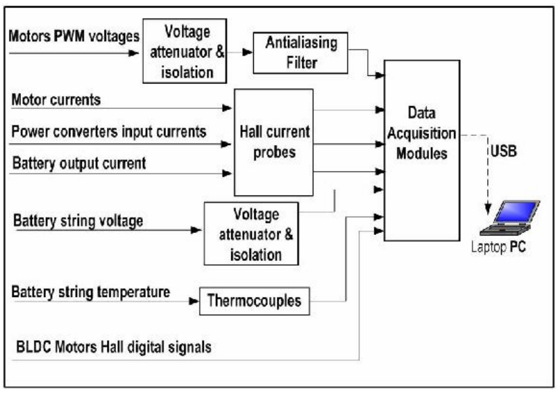

Fig.7. Hardware structure of the vehicle monitoring system

The quantities that are captured from the electrical drive under test are the following:

- two phase currents of each three-phase motor
- two line voltages of each three-phase motor – voltage attenuator and isolation amplifier
- input DC current of each Power Module
- battery output current
- battery voltage
- battery temperature
- the TTL signals at the output of each motor's Hall sensors (these sensors are incorporated in the BLDC motors and are used by the motor controller for determining the rotor angular position)

For current measurement there are used LEM-PR 430 Hall-effect current probes and voltage measurement it is used a DataForth SCMVAS signal conditioning module.

An anti-aliasing filter is used for the PWM voltage signals. This is a second-order Butterworth low-pass filter with 1 kHz cut-off frequency.

The above quantities are acquired using the National Instruments Compact-DAQ, a modular data acquisition system.

B. The Software Part

The software application, created using National Instruments LabVIEW, was designed to have the following main capabilities:

- to perform the on-line monitoring of drive-specific quantities in a clear manner;
- to provide an automatic and flexible data storage mechanism so that various events – which are based not only on the measured but also on the calculated quantities – can be utilized to trigger the data saving. This makes the storage memory to be more efficiently used, minimizing in the same time the user intervention during the drive tests;
- to be able to save significant amount of data at one time;
- to ensure a continuous data flow while performing the required monitoring tasks, taking into account that all these tasks – signal processing, displaying and other block-specific processing are time consuming when many signals are to be deal with.

The on-line processing includes also the calculation of the following quantities:

- the average values of the measured quantities,
- the speed of each motor, obtained from the digital signals provided by the Hall sensors,
- Battery state of charge (SOC), based on its dependence on the measured open-circuit voltage (the characteristic is provided by the battery producer).

Regarding the averaging, it should be noted that in this case, where the drive system includes Brushless DC motors, the acquired motor currents are firstly converted to the corresponding DC value using the information from the motor Hall sensors, and then the resulting DC value is averaged. In the case of using three-phase AC motors, this monitoring system calculates the average current by determining firstly its instantaneous magnitude using two phase currents [3], and then averaging that magnitude.

The main quantities which characterize the propulsion system performance can be visualized on a synoptic panel, presented in figure 8, where it is represented the propulsion system along with the indicators of the corresponding quantities during a test: speed, voltages, currents and battery state of charge.

The left side of the panel contains some driver-level indicators, as those present on an electric vehicle board: total and partial distance, instantaneous energy consumption expressed in kWh/km, a regenerative braking indicator, battery temperature and a fault indicator. The last one is connected to an error latch which is triggered if any of the following faults occurs: motors, power modules or battery long-term over current, battery over-temperature, under-voltage or over-voltage. The error latch can be manually reset. In future versions, the error source(s) will be conveniently displayed.

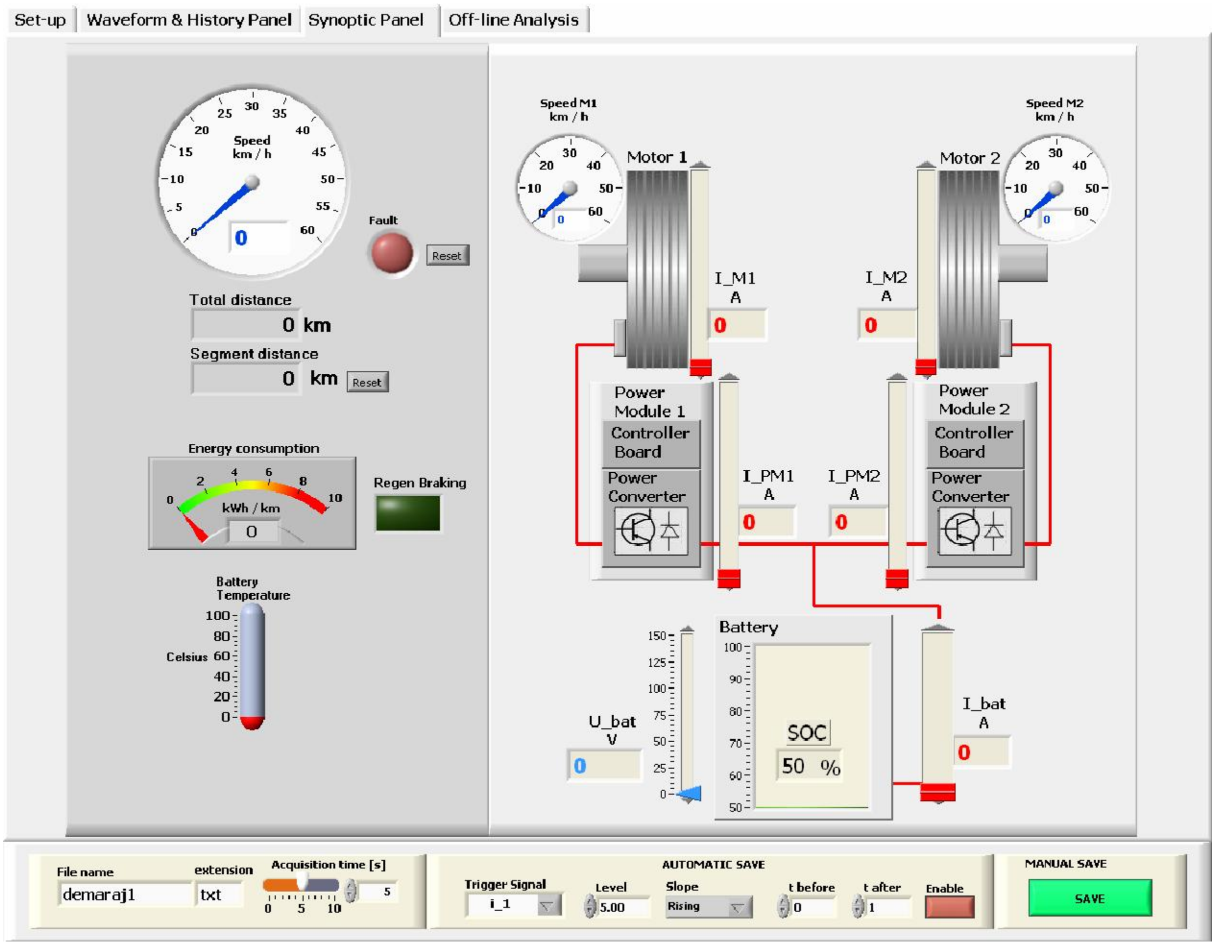

Fig.8. Synoptic panel illustrating the electric vehicle propulsion system and the corresponding quantities

The quantities evolution in time can be watched in another panel page, which contains a virtual oscilloscope and a history chart. In figure 9 it is presented a snap-shot of this panel, where on the oscilloscope (upper graph) appear the reference current and one of the phase currents, and the history chart shows the evolution of the averaged values of the battery and output current and one power module input current.

The oscilloscope can represent four of the whole number of the acquired signals at a time, and the user can switch between them at any moment. The maximum time-base width is 1 second.

In order to trace the quantities evolution for longer periods, a history chart was placed on the same panel. It displays the evolution of four averaged and decimated quantities in a time window, whose length can be modified through the time interval that is chosen for averaging.

On the same panel there are indicated – numerically and with sliders – eight averaged values, four of them being also displayed on the history chart.

At any time, during monitoring, the instantaneous values of the quantities can be saved both manually and automatically. In automatic mode, the user can choose any measured or calculated quantities to be used for triggering, specifying the desired level, slope, the time interval to be saved and the intervals before and after the trigger event. The files names are automatically suffixed when saved, so that minimum user intervention during tests is achieved.

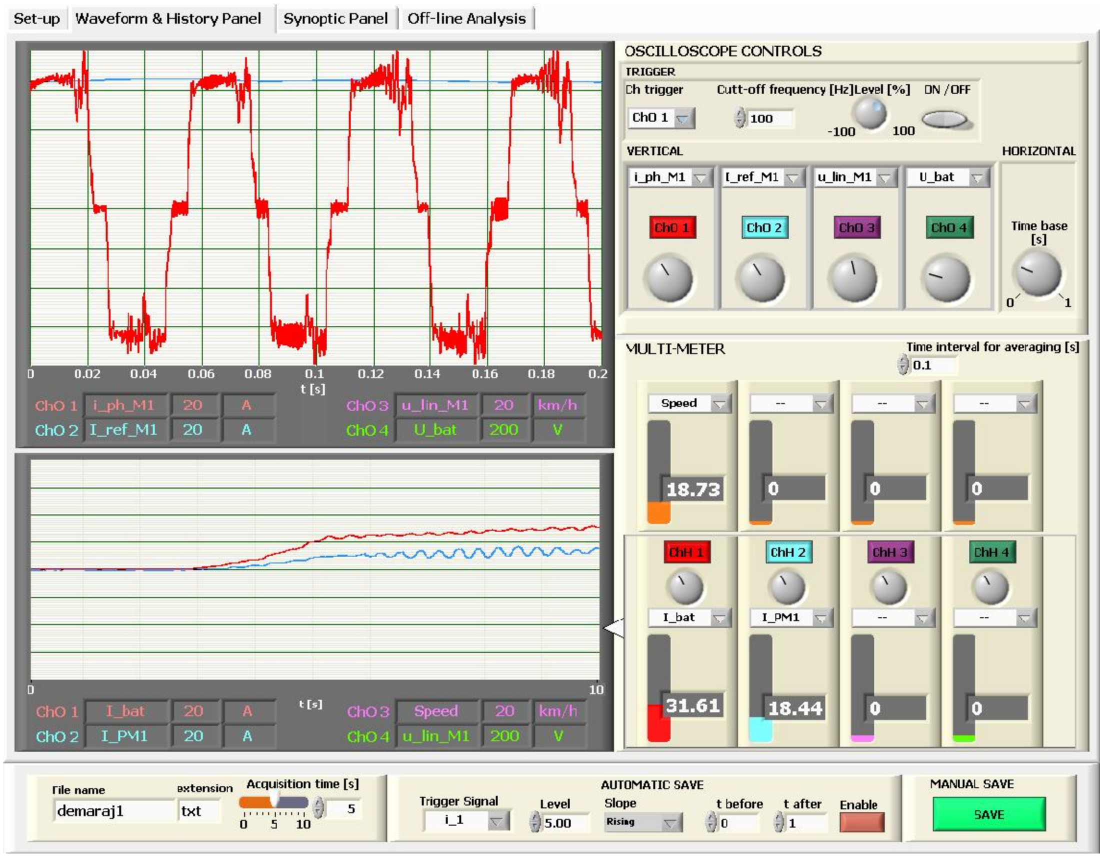

Fig.9. Waveforms and history panel

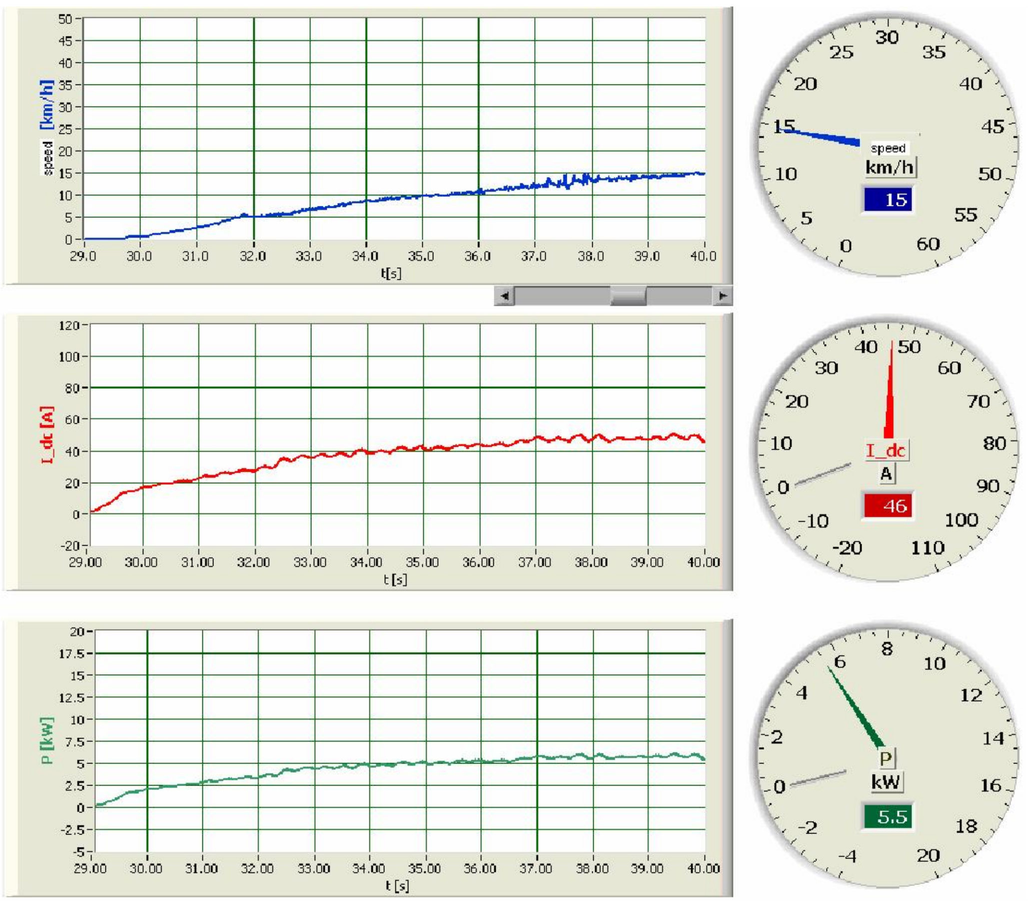

Fig. 10. Sample view of the off-line analysis panel showing the variation of the vehicle speed (up), and of the current (middle) and power (down) delivered by the batteries during vehicle start

While off-line, all the acquired quantities can be synchronously time-zoomed and scrolled, so that they can be analyzed in detail. A part of the off-line panel is presented in figure 10, where there are shown some of the test results from a vehicle start-up: the vehicle speed, and the current and electrical power delivered/absorbed by the battery.

6. USABILITY OF THE EXPERIMENTAL VEHICLE, REGARDING ENERGY MANAGEMENT ANALYSIS

As stated before, the experimental vehicle has a 100% electric, direct-drive propulsion system. For this type of propulsion, where no auxiliary combustion engine or switch gear are involved, the energy management has to deal mainly with the energy flow between the batteries and the motors, in both directions.

It is known that the most cost-sensitive part of the exclusive battery powered electric vehicles is the battery. Thus a good energy management must consider the factors that affect the battery life, such as the deep of discharge [5], the avoidance of under- and over-charging both in static and dynamic, regenerative braking charging. Therefore it is required a good estimation of the battery state of charge (SOC). A good SOC estimation provides many other advantages for Electric Vehicles: better battery performance, improved power system reliability, pre-failure warning of the battery pack, and consequently decreased costs. Moreover, a high-performance energy management may estimate the distance remaining until next necessary charging, using also SOC as primal information.

The state of charge of a battery is defined as the percentage of full charge capacity remaining in the battery. This information is identical to the combustion engine fuel gauge. In case of the EV, the SOC provides an indication of the amount of electrical energy remaining in the battery pack.

The SOC is accurately determined by the measurement of the stabilized open circuit voltage, V_0.

However, determination of SOC in dynamic driving conditions is difficult. The SOC under dynamic conditions can be expressed as in equation 1 [5]:

Eq. 1 $SOC = f_1(V_0) + f_2(I \cdot f_1(V_0)) + f_3(\Delta\theta)$

where: I is the discharge current,

V_0 is the open circuit voltage,

$\Delta\theta$ is the difference between the actual temperature and the temperature at which V_0 is specified,

f_1, f_2 and f_3 are functions of I, V_0 and $\Delta\theta$.

These functions are not generally known. Therefore the authors intended to use the capabilities of the experimental vehicle to perform organized drive tests in order to build a data base with the measurements collected in various operating regimes. This data base will then be used to construct parametric functions to fit the SOC behavior. The authors are currently working on this and the results will be presented in future papers.

Regardless the method used for SOC calculation, the electric vehicle management system uses it to perform many of its functions.

7. CONCLUSION

This paper presented an experimental vehicle that was realized for testing the vehicles electric drives. It contains a mechanical structure, programmable power converters and a PC-aided monitoring system which allows on-line viewing the quantities characterizing the electric propulsion performance. Based on its capabilities, the experimental vehicle can be used for performing organized tests in order to build a meaningful database of measurements for research on propulsion systems and their energy management.

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