Low Cost Battery Management System

Z. Slanina, J. Dedek, and M. Golembiovsky
VSB-TU Ostrava, 17. Listpadu 15, 70833, Ostrava-Poruba, Czech Republic.
Zdenek.slanina@vsb.cz

***Abstract*—This article addresses the issue of battery management system for the development of an electric scooter. Considering developing electric vehicle needs big financial supports, the development of the electric scooter is an educational project conducted at the Technical University of Ostrava. Electric scooter is equipped with a brushless motor with permanent magnets and engine controller, measuring and monitoring system for speed regulation, energy flow control and both online and off-line data analysis, visualization system for real-time diagnostics and battery management with balancing modules system. Implementing these devices to develop an electric vehicle brings a wide area of scientific research. As a part of the project for electric scooter development, a battery management system which oversees the running parameters of the accumulator was developed at the university. The function of the balance module, especially its software, will be described in this article.**

***Index Terms*—Electric Scooter; BLDC Motor; Control; Visualization; Balancing Unit; BMS.**

I. INTRODUCTION

Research and development of prototypes connected with alternative energy sources has a long tradition at the Technical University of Ostrava. Among the first result of the non-combustion motor experiments was the Hydrogenix vehicle (using hydrogen as an energy carrier and electric DC motor as the drive unit) which was presented as the work of researchers and students at the Shell Eco-Marathon competition in the year 2004, 2005 and 2009. This was followed by further studies and prototypes that were finalized with the electric sports car Kaipan in 2012 in four functional versions [1–3]. The biggest problem with these results is the lack of funds for additional maintenance and research. Consequently, an implementation of new the electric vehicle without heavy financial restrictions especially for educational purposes was carried out. This initiative involves the conduct of experiments related to the use of wide area of electro-mobility. [2], [4–6].

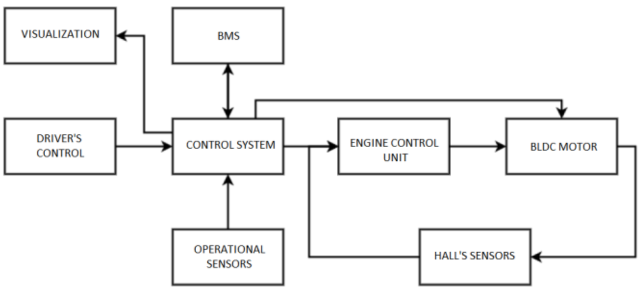

Figure 1: Basic idea of new electric vehicle – electric scooter

Electric scooter is a device that is structurally quite simple and from this reason it was chosen as the aim of the research and development work. Now it is possible to focus primarily on measuring and control systems and their realization. Ideological diagram of electric scooter is shown in Figure 1. The system consists of several modules involving the control of other parts of the issue with the central management in the first prototype. All components used for the implementation are described in the following sections.

II. MOTOR FOR ELECTRIC SCOOTER

For the current version of electric scooter, BLDC motor, which is the successor of DC commutator motors was selected. In the case of permanent magnet version, we selected sufficient mode of operation and acknowledged their limited performance that guarantees safe operation. The control of this motor can be used in two ways - scalar or vector control. Scalar control is attractive due to its simplicity and the absence of large number of sensors and the ease of the control system needed for regulation. In this case, vector control with its better performance, was selected to improve the dynamics. It is also possible to operate the engine in delta-star modes.

The engine was chosen for direct integration into the wheel, as shown in Figure 2. The big radius of engine allows high torque even without mechanical transmission; therefore, direct join of driving system and wheel was made. However, the purchased drive has disadvantages, particularly low operating speeds that limit the maximum speed of electric scooter. Motor voltage was thus increased to 48 V and the final engine was adapted for the possibility of switching to delta-star modes during its operation. The mechanical adjustments were very complicated in laboratory conditions, but the engine was finally adjusted to the desired properties. For switching between modes, relays for voltage 24-48V and currents in the tens of amperes were used.

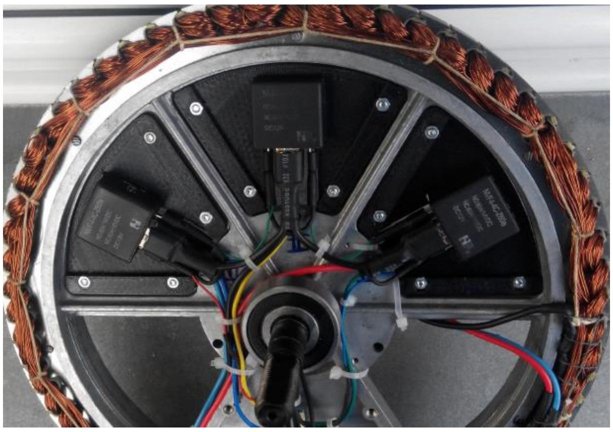

Figure 2: Improved solution of embedded BLDC motor

The commercial MagicPie conversion unit was used as a control unit. This allows for the scalar control and it is sufficient to conduct the basic tests. In the future, this unit will be replaced by its own solution with vector control to ensure the above-mentioned dynamics of movement.

III. CONTROL AND VISUALIZATION SYSTEM

The control system unit centralizes the management of the entire electric scooter and it is interconnected to other measuring and control parts. This unit is directly connected to the engine control. The next part is the sensors for monitoring operating parameters of scooter, such as the temperature, humidity, scooter speed and a GPS unit, which was used for online monitoring of scooter movement. It is also the possibility to integrate Bluetooth module to send data to smart devices, GPRS module for online monitoring of process data or data logger for off-line data storage [7,8]. Another part of the control unit is the input buttons from the driver. They allow to switch modes of the electric scooter, ensuring the hooter, cruise, lights and signals control and visualization screens change. Finally, the following section describes the BMS connection.

The visualization interface of electric scooter is minimized in terms of display size. A graphical LCD display was selected for this purposes. It is possible to display data of the central control unit. Visualization device consists of control buttons too. The data processing for displaying operational data (Figure 3) is fast enough. Further, from the driver's perspective, the presence of mechanical buttons instead of touch display solution is much more acceptable (these were confirmed during the use of touch screens for sport oriented vehicles, for example the mechanical controls are beneficial for the sport mode as in Kaipan car).

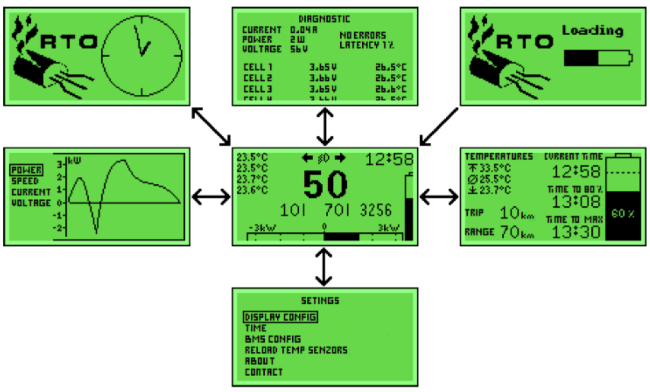

Figure 3: Visualization screen snapshots

IV. BATTERY BALANCING SYSTEM

In the context of the operation of the electric vehicles, there is a large attention on accumulator choice (see Table 1) and its operation [9]. For the needs of electromobility, three basic types of accumulators can be used:

- Lead-acid battery - required by automobile starter motors and maintenance free
- Ni-MH technology - more powerful, memory effect and big self-discharge current
- Li-ION technology - high energy density

They are loaded with great dynamics cycling or transition from phase discharging into the charging status. Failure to follow some basic principles can lead to very rapid wear and battery aging leading to possible distortion or fire. For this reason, BMS (Battery Management System) has been developed for the realization of electric scooter [2]. BMS is composed of two basic parts - balancing module (fasten to each accumulator) and monitoring unit (central BMS unit).

Table 1
Comparison of three power sources for electric scooter

		Pb-acid	NiMH	Li-ion
Theoretical	Voltage [V]	1.93	1.35	4.1
	Specific energy [Wh/kg]	166	240	410
Practical	Specific energy [Wh/kg]	35	75	150
	Energy density [Wh/L]	70	240	400
	Energy efficiency [Wh/L]	065-0.7	0.55-0.65	~0.8
	Power density [W/L]	450	> 300	> 800

The basic function of the balancing modules is to protect against overcharging. This is mostly realized with the engagement of the switch transistor that disconnects the appliance in the form of accumulator at the limit value, and it redirects the excess energy into the resistor (other load). In the case of energy decrease, it is again connected to the battery. However, this method does not protect against battery undercharging. There is a need to use a more sophisticated method of battery power that decreases monitoring. For this purpose, it is possible to use decentralized solution where individual balancing modules are connected with accumulators. They take control over the battery charging or discharging and they transmit data to the monitoring master unit. It makes also diagnostics of the whole current that goes through the entire batteries. In the case of arising problems, it allows to disconnect individual batteries completely and protects all equipment against over current and short circuit etc. Data from central monitoring unit can be watched on some visualization system, which was mentioned in the previous section.

There are several commercial solutions available on the market. However, the price, availability and service possibilities are not satisfactory for the experiments; therefore, we developed our own balancing system, as shown in Figure 4.

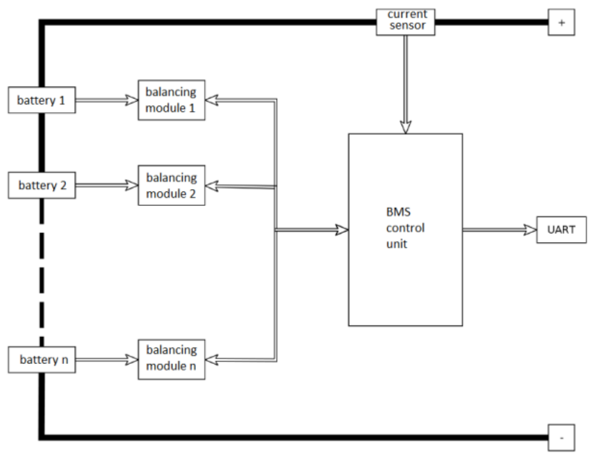

Figure 4: Battery management system

The main task of the balancing module is measuring the voltage and battery temperature and balancing in the final stage of charging. An important parameter is also measuring the pressure in the accumulators. However, the measurement due to the construction of the battery impossible as the whole current measurement is the task of the central BMS unit. Balancing module control is realized by Atmel microcontroller. Peripherals, mainly the AD converter and communication interfaces must be taken into account for correct microcontroller analysis. Atmel Tiny was chosen from the low cost microcontrollers with the possibility to implement and use the interfaces mentioned. Further, a single pin for bidirectional communication was used for communication due to the low pin count microcontroller as this solution is considered sufficient. Another type of communication that allows a serial communication supported by hardware (USART - Universal Synchronous / Asynchronous Receiver and Transmitter) was selected in the final version. Although the price of this chip was not significantly increased the balancing unit is still galvanic isolated from the central BMS.

For the power of the balancing unit a transistor working in a linear mode was used mainly to maintain a constant voltage on the battery. From the given parameters of the maximum cell voltage $U_{bal} = 3.6V$ and 500 m, a balancing current is done for the final power dissipation. This is needed, in case the balancing is transferred to the resistor:

$$P_{bal} = U_{bal} \cdot I_{bal} = 500 \cdot 10 - 3 \cdot 3.6 = 1.8W \qquad (1)$$

PNP transistor was chosen as an active element because of its low power voltage and negative contact used for heat drain. For optimum operation, a residual power was divided into resistor and transistor with 80% of nominal load. PNP transistor is controlled by PWM signal produced by microcontroller.

For communication, it is necessary to use galvanic isolation and in this case, the circuit PC817 was used as optocoupler. BMS control unit uses cyclic communication (see Figure 5) with all the balancing modules in the system. Communication is controlled by master/slave principle. In the case of bad or no answer, BMS central unit activates the message to a higher or visualization system about this problem. BMS can sleep all the balancing units in the system if electric scooter is inactive. It brings lower consumption if the balancing functions are not needed. For service purposes, the implemented messages allow the change of balancing unit address and process of limited settings.

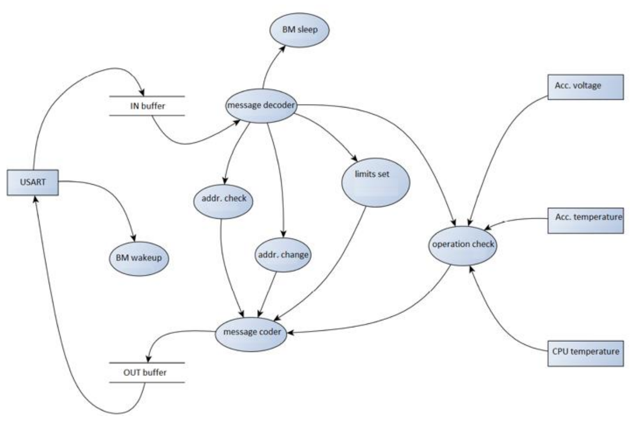

Figure 5: Data flow diagram of balancing system application

The second option for balancing modules is using wireless communication [10,11]. This solution has one main advantage - there is only power wires inside in the battery pack. Based on previous experience, the previous electric vehicles communication lines have many problems with power lines. Connectors which are inserted into the socket are very often moved out with the existence of inequality road, thus creating vibrations. It is very complicated to find which plug has been poorly inserted. For example, it is also joined with manual switch address configuration. The quality of the switch is changing in time, and although the switch looks like it is set up correctly, it is not electrically. BMS very often reports the missing balancing module, hence it increases the chance of destroying the accumulator. Wireless solution is possible because communication is done by master/slave mode with cyclic that addresses all balancing modules. In this case, wireless modules nRF24L01+ was tested. Communication was successful, but integration into the existing solution is not effective. Two main reasons that cause this problem are the price of module and the way of using the module. In our case, communication pins was used as a driver between the USART and the wireless technology. However, the module itself contains microcontroller, which is usable for standalone application. It is the task for future experimental work.

BMS central unit is implemented using a microcontroller ATmega 2560. The main objective of the unit is to prevent damage to the battery pack based on three ways:

- overcharge protection - It is realized by balancing the modules, but the BMS control unit can help to reduce the electric power supplied during charging process, thus treating radiation at the resistors
- protection against undercharging - In the case of low voltage battery, the BMS unit is able to disconnect the load
- overcurrent protection - In the case of overcurrent, the BS control unit must ensure to disconnect the load
- thermal protection - If the temperature is over the limit, BMS control unit must disconnect the load

The hardware of BMS central unit also allows to measure the current between -75 and 75 A. This possibility exists for recuperation process planned in the future. DC relay switch is used with the contactor controlled by digital output of the microcontroller boosted by the switching transistor.

Reports that send information about the battery voltage and temperature and reading or setting of limit values are also used for superior system communication and visualization.

V. BMS SOFTWARE

The task of program equipment of the balancer can be divided into several simple sections, which communicate with each other. The main advantage of this approach is its implementation, as individual blocks can be programmed and tested independently. However, in order to succeed in using this approach, it is necessary to premeditate on the division of individual parts and their communication, as any later changes are very difficult to implement, especially if it is a large-scale change. In such cases, the easiest option is to start the implementation from scratch. Here is the communication protocol:

* <type of message><data 1>;...;<data n>;<CRC>;

1. * – start byte

2. Type of message – one ASCII symbol except *
3. data – hexadecimal number coded in ASCII
4. data frames division
5. CRC – hexadecimal number coded in ASCII

VI. SYSTEM DESCRIPTION

The balance module provides measuring the voltage and temperature on accumulator cell, reduction of voltage in case the cell is fully charged and communication with superordinate control system. All these requirements are divided into two units although certain information is shared among these two units.

A. Cell parameters measuring and voltage balancing

This section deals with the monitoring of the running parameters of the cells, its evaluation and control of the cell balancing. It can operate independently even without active communication, in case the balance module was not put into low energy consumption mode by a superordinate system.

In order for all the operations in this part to be correct, they are run in predefined moments using a timer. The first step is measuring the running parameters using A/D converter. The data measured are the cell temperature, voltage and microcontroller temperature. To limit interference, the measured data were filtered using FIR filter of the SMA type, which analyzes 10 sequential measurements. Information about the measured voltage was then processed by regulator type I, which has the function to keep the cell voltage under set limit (3.6V for Li-FePO4). The period for calculating the action intervention of this regulator is 20 times longer than the period of measurement, in order for the change of voltage caused by the last action intervention to go through FIR filter all the way into the regulator input. Regulator type I was chosen due to its simple implementation and zero regulatory deviation in stationary state.

VII. CONCLUSION

Building an electrical scooter prototype is a complex engineering work. The mechanical work and improvements that accompanied the built of the scooter is beyond the scope of this paper. From electrical or electronic point of view, there is interesting realization of battery management system and BLDC motor control which should be replaced by a more modern way of vector control. Due to the open configuration, it is not possible to summarize the overall parameters of electric scooter. However, it is interesting (Figure 6) to focus on the laboratory tasks [12-14].

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Figure 6: Realized electric scooter during last tests.

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