Alternatives for a design of a Battery Management System for traction applications

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Abstract: - It has developed a battery management system that optimizes the performance of the batteries and performs an exhaustive monitoring of the process of loading and unloading them. It is a prototype of BMS that optimizes the use of batteries and provides an adequate power for an electric vehicle. It manages loading and unloading processes, and it can be used to ensure the safety of the battery and prolong its life. It has been developed a tracking system for the batteries by measuring the most important parameters in battery charging / discharging. This system will allow to match the cells in an efficient way and will provide detailed information about the battery and its operation over time. It has a system that accurately measures the voltages, so you can check the performance and lifetime of the cells. To measure the voltages created in the stacks of large cells, an integrated circuit of Linear Technology is chosen. A designed system that meets the design specifications and that works well.

Key-Words: - Battery management system, traction applications, electric vehicle.

1 Introduction

In traction applications, operating systems are significantly increasing off- grid: industrial vehicles, commercial vehicles, motorcycles, electric vehicles, etc. [1-3].

In many of them, you set the BMS (Battery Management System) to optimize the use of batteries and the proper use of energy. The advantages of the system are that, managing the process of charging and discharging of the batteries, safety is guaranteed on the one hand and on the other hand it prolongs the battery life. These advantages mean a lower overall economic cost and a more efficient use of energy [4].

In addition, there is a growing social demand for clean technologies, more respectful of the environment, that make it particularly desirable to develop electric vehicles.

On the other hand, in recent years new applications have been designed (electric vehicles, photovoltaic systems, uninterruptible power supplies, etc.) that have led to the emergence and development of new battery technologies, more efficient and reliable.

Moreover, energy management embodies engineering, design, applications, operation, and maintenance of electrical power system to provide for the optimal use of the electrical energy. Optimal in this case refers to the design or the modification of a system to use minimum overall energy where the potential or real energy savings are justified on an economic or cost benefit basis. Optimization also involves factors such as comfort, healthful working conditions, the practical aspects of productivity, aesthetic acceptability of the space, and public relations. [5]

2 Objectives and applications of BMS

The traction battery in a hybrid electric vehicle (HEV) is a complex system consisting of many single cells and an especially designed electrical/electronic circuit [6]. Part of that circuit - and by far the most critical due to its complicated calibration - is the battery management system (BMS). This supervising control unit processes the actual status of the cells of the traction battery and shares the computed data set with the rest of the vehicle's controllers (in particular with the hybrid control unit, HCU). It determines the major operational tasks of the traction battery as are available power and energy, high reliability (long cycle and long calendar life), and battery safety

under any circumstances (i.e. use and abuse cases). Achieving these goals is widely connected to the quality of the battery management system and its interaction with the other vehicle control units, [7, 8].

Among the functions of a BMS, we can highlight the battery management and to ensure a proper operation of the battery. Power management includes features that reduce power consumption in parts of the system with regard to hardware and software design, for example reduce or turn off components when not in use. The BMS may simply be a battery monitoring, keeping track of the parameters or maintaining control of them during loading and discharging, such as voltage, current, internal temperature of the battery and environmental temperature [9].

These systems include not only the monitoring and protection of the battery, but also there are methods to keep it prepared to deliver the maximum power when needed and extend the life of the system. It must interact with other systems, such as engine management, temperature control, communications and security systems.

There are three main objectives in all battery management systems: to protect the cell or battery pack against damage, prolonging the life of the battery, and keep the battery in a state where it can comply with the requirements for which it has specified.

2.1   BMS for an electric vehicle

In the automotive field, the functions of a BMS for electric or hybrid vehicle are as follows: [10]

- Monitoring of the conditions of the cells that comprise the battery.
- Maintenance of all cells within the operating limits.
- Protection of the cells according to their tolerance conditions.
- Provide a "Fail Safe" system. Mechanism that if uncontrolled conditions blocks the electrical system partially or completely.
- Isolation of the battery in an emergency. (For example, overheating).
- The compensation from imbalances in the parameters of cell.
- Provide information on the State of charge (SoC) of the battery. [11]
- Provide information on the state of health (SoH) of the battery. [12]
- Prediction of autonomy with the charge remaining in the battery.

- Providing optimum charging algorithm for loading the cells, depending on their characteristics and the type of chemistry involved.
- Provide means of access to get to the cells in an individual way. That is, loading of some cells without having to make it on the rest.
- Mode "reduced or low performance" in the event of cell failure or once below the minimum voltage.

3   Development

Throughout the planning process and development of this BMS, different alternatives have been considered, whose study is detailed below. We provide a description of the alternatives evaluated together with the aspects that were taken into account in the selection of the solution.

For the choice of the most suitable option, it should take into account that the development and design of a battery management and monitoring system has focused on its use in an electric vehicle.

It has to take into account the available hardware (BMS, etc.) for the design and development of each part of the system at any time by choosing the option that best suits the characteristics and features of these parts.

3.1   Communication protocols between system modules

3.1.1 Alternatives

The following describes briefly the possible alternatives of communication buses and protocols that could be used to communicate the different modules of the system:

- **SPI bus:**

The SPI bus is a communications standard, mainly used for transferring information between integrated circuits in electronic equipment. This is a transmission protocol of synchronous serial data (bits), that is, regulated by a clock.

It includes a clock line, incoming data, outgoing data and chip select pin, which enables or disables the operation of the device with which you want to communicate.

The advantage of a serial bus is that it minimizes the number of conductors, pins and size of the integrated circuit.

Its advantages include the possibility of Full Duplex communication (that is, bi-directional), faster than I2C and simplicity. On the other hand, it requires a large number of pins, it is not entirely sure (there is no confirmation from the receiver) and there is no flow control via hardware. [13]

- **I2C bus:**

I2C is another serial communications bus, bi-directional too, with two-wire, developed at the time by Philips. Its main purpose is to be able to facilitate communication between small devices, such as between PICs and EEPROMs. It is a bus widely used in industry, mainly for communicating microcontrollers and their peripherals in integrated systems, but especially to communicate integrated circuits that normally reside on the same PCB (printed circuit board).

The main feature of I2C is that it uses two lines to transmit information: one for data and one for clock signal. It is also necessary a third line as a reference. Other features include the lower speed, lower number of required pins and it is based on the addresses of the devices.

- **CAN bus:**

The CAN bus is a serial data communication bus, used for its application in real-time distributed systems. CAN bus was originally developed for applications in the automotive industry, but because of its features, robustness and excellent quality/price, CAN was adopted for industrial and control applications.

The CAN communication protocol was originally specified by the German company Robert Bosch for critical applications in real time. Among its advantages are the following:

- Highly effective error handling. It is a very robust protocol against noise problems, as it was designed for industrial environments.
- Ease of development and a large number of manufacturers in the CAN device market.
- Its "non –destructive" priority system allows that, if two messages are transmitted simultaneously, this of higher priority is not destroyed and reaches its destination without any delay added.
- Its message identification system is that the nodes do not really have a direction, but they are programmed with a filter system in order to accept a certain type of messages, that is, it is a message-based system instead of directions, making new nodes can be added without reconfiguring the rest of the nodes. [14]

3.1.2 Selection criteria

The following will detail the criteria that are taken into account when selecting the communication protocol between the different modules of the system:

- **Simplicity**:

It is important that the chosen protocol is simple, both when programming the various devices involved in the system and the amount of hardware (wiring, power supplies, etc.) necessary to form the complete system.

- **Robustness**:

Since some parameters to be monitored are critical to vehicle operation and safety of the people around it, it is vital that the number of lost data during the communication is minimized. In addition, the environment in which the system is installed, with motors and batteries of high voltage, requires the system to be as immune as possible to noise.

- **Compatibility with other elements involved in the system:**

The presence of hardware involved in the system makes it necessary to take into account the compatibility between the different equipment. Moreover, it is important to avoid that the number of communication protocols involved in the system is very high. So it is necessary to try to standardize communications between devices of the vehicle as much as possible.

Below it is shown a table which values weighted the above mentioned criteria.

The score for each of the alternatives according to each criterion is done by assigning a number from 0 to 10, with 10 being the value representing maximum compliance with the criterion and 0 null the same compliance.

In the last row of the table is an overall, a global assessment, considering all the scores according to the percentage of importance that is assigned to each of the criteria.

PARAMETERS	WEIGHT	SPI	I2C	CAN
Simplicity	15%	10	10	6
Robustness	25%	5	5	10
Compatibility with other elements of the system	60%	5	3	10
Globally	100%	5,75	4,55	9,4

Table 1: weighting of communication protocols

3.3 Batteries
3.3.1 Alternatives
The BMS design implemented is intended for traction applications. Among the different types of batteries used for these applications, the most prominent are: the lead-acid (Pb-acid), nickel cadmium (Ni-Cd), nickel metal hydride (Ni-MH) and lithium ion (Li-Ion). The following table collects different characteristics of each of them:

	Pb-acid	Ni-Cd	Ni-MH	Li-Ion
Voltage (V/cell)	2	1.2	1.2	4
Specific Energy (Wh/Kg)	40	60	90	140
Specific Power (W/Kg)	150-300	80-150	200-300	420
Energy density (Wh/l)	80	95	150	290
Auto discharge (% per month)	4-6	10	15-25	2
Life (cycles)	500-600	>1500	>1200	500-1000
Cost (€/Kwh)	120-150	250-350	300-345	500

Table 3: Characteristics of each type of stacks

3.3.2 Selection criteria
When choosing a type of battery for any application, we should consider the following features:
- Long life (more than 1000 cycles).
- Low self-discharge.
- Low cost.
- Minimum maintenance.

In addition, batteries designed for traction systems should have the following characteristics:
- High energy density and high specific energy, for low-volume and low-weight systems.
- High specific power.
- Capacity to work in hot conditions.
- Resistance against bad conditions, like vibration or shock.

3.3.3 Selection of the solution
Given these conditions the batteries that should be more suitable are of lithium, since all the conditions mentioned above.

The first communication tests are performed by means of a resistor ladder, shown in Fig. 1, and a power supply for controlling the voltages that we must read and for not damaging the battery or one of the microcontrollers.
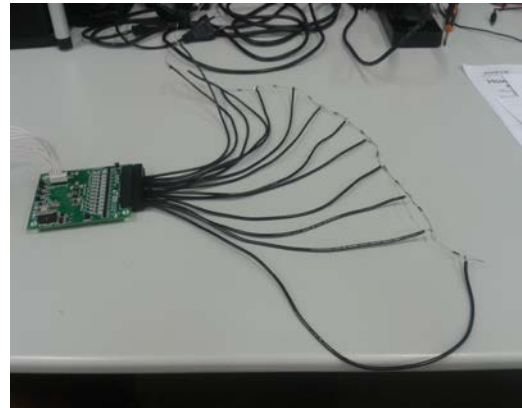

Fig.1: Resistor ladder

A resistor ladder is an electrical circuit made of repeating units of resistors. In this case, we alternate two possible values, where a value should be double the other. There are several possible configurations. Through the resistor ladder, we can, in a simple and economical way, to implement a digital-analog converter, linking groups of resistances alternating possible values on a ladder. A diagram of a resistor ladder is shown in Fig. 2.
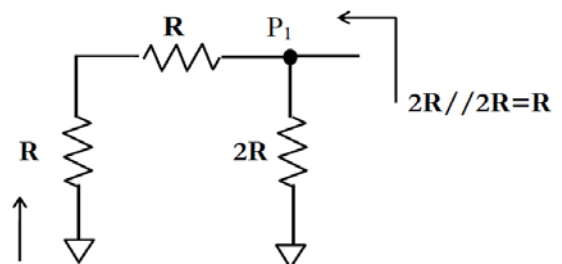

Fig.2: Diagram of a resistor ladder

4 Conclusion
It is very common that in the last years traction applications work with batteries. Not only for traction applications such as electric vehicles, but also for other devices. In this sense, batteries have taken more center stage and therefore the systems

called battery management systems (BMS). We have studied different alternatives for the design and development of one of such BMS in order to be applied to an electrical vehicle that is developed in our university. We have defined the components and tasks of the most suitable BMS for our vehicle, made and evaluated with good results. In this paper, the design among different alternatives is presented.

References:
[1] Arnau Vives A., Ferrero y De Loma Osorio J.M., Jiménez Jiménez Y., Sogorb Devesa T., *Sistemas Electrónicos de Comiunicaciones II. Capítulo 9. Bucles de enganche de fase (PLLs).* EHU/UPV, 2000.

[2] Berdicheevsky, G., Kelty, K., Straubel, J.B., and Toomre, E., *The Tesla Roadster Battery System*, 2006, available in http://webarchive.teslamotors.com/display_data /TeslaRoadsterBatterySystem.pdf (October 2013).

[3] Stuart T., Wang X., Ashtiani C., Pesaran A., *A modular Battery Management System for HEVs*, The University of Toledo, Ohio, USA, June 2002.

[4] Richard J .Fowler, *Electricidad: principios y aplicaciones* (in Spanish, *Electricity: principles and applications*), Editorial Reverté, 1994. ISBN: 8429130284.

[5] Lou Wenzhong, Yu Xiuli, Wheel Robert Energy Management System Based on Intelligent, *Proceedings of the 2007 WSEAS International Conference on Computer Engineering and Applications*, Gold Coast, Australia, January 17-19 2007.

[6] Christoph Hametner, Johannes Unger and Stefan Jakubek, Local Model Network based Dynamic Battery Cell Model Identification, *Recent Researches in Circuits, Systems, Multimedia and Automatic Control*, 2012.

[7] D. Lim and A. Anbuky, A CAN-based battery management network: design, analysis, modelling and simulation. *Factory Communication Systems, 2004. Proceedings. 2004 IEEE International Workshop on*, pages 291–295, Sept. 2004.

[8] J. Chatzakis, K. Kalaitzakis, N.C. Voulgaris, and S.N. Manias, Designing a new generalized battery management system. *Industrial Electronics, IEEE Transactions on*, 50(5): 990 – 999, Oct. 2003.

[9] Electropaedia, http://www.mpoweruk.com/bms.htm, información sobre los sistemas de gestión de baterías.

[10] Wikipedia, La enciclopedia libre. "Batería (electricidad)".Web/URLs: http://es.wikipedia.org

[11] http://www.mpoweruk.com/soc.htm "State of Charge (SOC) Determination" in October 2013.

[12] http://www.mpoweruk.com/soh.htm "State of Health (SOH) Determination" in October 2013.

[13] Comunicación SPI, www.i-micro.com/pdf/articulos/spi.pdf

[14] Comunicación CAN, http://www.can-cia.org/can/standardization/standards.html/

[15] Arduino, Arduino Website. http://www.arduino.cc/es