Choosing communication protocols, microcontrollers and batteries in the use of a BMS

Javier Bilbao, Concepción Varela, Eugenio Bravo, Miguel Rodríguez, Olatz García, and Purificación González

***Abstract*—**Traction applications in automotive have traditionally used lead acid batteries. However, the situation is changing as new battery chemistries and supporting technologies have brought with them new technical and economic benefits, making battery power viable and more accessible for traction applications that were previously uneconomic or impractical. So, traction applications, and particularly electric vehicles, are being increasing their popularity with new type of batteries. In this case, electric cars use the energy stored in a battery (or series of batteries) for vehicle propulsion. Electric motors provide a clean and safe alternative to the internal combustion engine. Obviously, with the new technology for batteries some systems to improve them are arising. At the present, systems for monitoring and managing these batteries are common. In this article we summarize the Battery Management Systems and present some choices for some of the parts of these systems: communication protocols, microcontrollers, and the batteries.

***Keywords*—**Battery management system, traction applications, electric vehicles, communication protocols, microcontroller, monitoring.

I. Introduction

THE increase of energy density and efficiency, and accurate measurement of the state-of-charge, etc. are important research topics [1], [2]. Although many new electrochemical systems are under study for this application, the lead acid battery is still a leading candidate [3]. In traction applications, operating systems are significantly increasing off-grid: industrial vehicles, commercial vehicles, motorcycles, electric vehicles, etc. [4]-[6].

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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 [7].

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. [8]

II. 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 [9]. 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, [10], [11].

The battery management system may be for example a solar photovoltaic power supply system for Dynamic Line Rating (DLR) on-line monitoring system. The DLR system is designed to improve the transmission capacity of overhead lines, which decreases or delays to re-build transmission lines. The system is composed of sampling terminals installed on dead-end configuration of a line and one control instrument equipped in dispatch center [12].

The BMS would include the capacity selection for PV array, rechargeable battery pack, maximum power point tracking for PV array, charge and discharge method for battery pack. Under different temperature and light intensity, MPPT (Maximum Power Point Tracking) strategy can always obtain the highest possible power from PV array, which ensures the charge efficiency of battery pack. The charge and discharge method effectively extend the life of battery pack. Designed and realized the I2C line agreement which was used to communicate between the CPU of the power supply system and the CPU of the data acquisition system. The capacity of PV array and battery was selected according to the need of the power consumption of devices and the weather condition.

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 [13].

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.

A. BMS for an Electric Vehicle

According to Gusikhin et al. [14], a vehicle can be defined “intelligent” if it is able to sense its own status and that of the environment, to communicate with the environment and to plan and execute appropriate maneuvers. The first application of intelligent vehicle systems has been the increase of safety by providing driver assistance in critical moments. A combination of on-board cameras, radars, lidars, digital maps, communication from other vehicles or highway systems are used to perform lane departure warning, adaptive cruise control, parallel parking assistants, crash warning, automated crash avoidance, intelligent parking systems [15].

Markel et al. [16] studied the effect of integration between an electrified vehicle fleet and the electric grid in order to increase the amount of renewable energy used to power the electric vehicles by optimizing the timing and the power of the charging processes during the day.

In the automotive field, the functions of a BMS for electric or hybrid vehicle are as follows: [17]

- 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. [18]
- Provide information on the state of health (SoH) of the battery. [19]
- 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.

Instead of using BMS, there are some alternative methods for a good management of the batteries. For instance, providing rest periods is essentially a way of distressing the cells or the battery. There are other alternative ways of accomplishing this. The cycle life can be increased by reducing the charge level on the cells [20].

But there are drawbacks to this solution. The number of cells must be increased in proportion to make up for the decreased cell capacity resulting from the lower charge level. The battery energy density is reduced since the cells are not used at their full capacity. Reliability is reduced because there will be more cells in the chain and a single cell failure will cause failure of the battery.

At the present, BMS is the best solution, where some processes like the SOC are vital for the life of the battery. For battery-powered motorcycles (BPMs) which use the lead acid battery as its power source, the discharge of the battery is irregular so there is no single method that can precisely measure the SOC of the lead acid battery. Hence, the studies usually adopt the combination of several measurement methods to compensate the disadvantage of each method [21].

When the battery is loaded, the reaction of the electrode will cause the internal loss of the battery due to the direct connection between the electrode reaction and the current of the load. Thus, with this approach, the additive effect due to the battery aging and discharge current can be obtained. Then the electrochemical theory is used to calculate the resistance effect by the electrode reaction to estimate the internal loss of the battery. As a result, the SOC of the battery can be accurately calculated in real time.

III. 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.

IV. Communication protocols between system modules

A. 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 [22].

- **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 [23].

B. 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.

Table I: weighting of communication protocols

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**

C. Selection of the Solution

In the above table, it can be seen that in the overall count the CAN protocol is most suitable because it presents a higher robustness than the other two protocols and it is compatible with the other hardware involved. In addition, it allows to add modules to the system without new reconfiguration. Furthermore, the compression may take longer than the other two protocols, but this task will equally be necessary because the BMS provides its data through this bus.

V. MICROCONTROLLERS

A. Alternatives

Below we describe briefly different families of microcontrollers that might be used to manage the different modules that make up the system:

- **PIC:**

The PIC are a family of microcontrollers RISC (reduced instruction set computer) type manufactured by Microchip Technology Inc. The PIC uses a set of instructions that may vary from 35 for low-end PICs to 70 for the high end. Microchip provides a freeware development environment called MPLAB which includes a software simulator and an assembler. Other companies develop C and Basic compilers.

- **Arduino:**

Arduino is an open electronic platform for prototyping based on flexible software and hardware, and easy to use. It was created for teachers, designers, hobbyists, artists and anyone interested in creating interactive objects or environments. Arduino can take information from the environment through its input pins of a whole range of batteries and can affect what surrounds it controlling lights, motors, and other actuators.

The Arduino microcontroller is programmed using the Arduino programming language (very similar to C) and the Arduino development environment (processing). The boards can be made by hand or purchased factory assembled; the software can be downloaded for free. The reference design files (CAD) are available under an open license [24].

- **Atmel (AT90CAN):**

AT90CAN is a family of microcontrollers manufactured by Atmel. They are characterized by a wide performance and low power consumption. Also, they use a RISC architecture and have a set of 133 instructions. They have a CAN controller and can be programmed in assembly language and C.

B. Selection Criteria

Below is listed the criteria to take into account for the selection of the most suitable option:

- **Simplicity**:

It is interesting that microcontrollers are simple to operate and program. Therefore, programming in assembly language will be avoided for being more costly and cumbersome.

- Availability of reusable code:

It is interesting to have reusable code in order to save development time when programming devices. The large presence of examples in the net for some families may make it easier to familiarize with their use and avoid problems due to the lack of support.

- Support for necessary communication protocols:

We must take into account that using microcontrollers have the number of inputs and outputs at least needed to connect all the devices to manage and that also support all communication protocols (CAN for the rest of the modules of the system, SPI or others to control...), preferably without additional modules.

Below it is shown the table that values weighted the criteria previously mentioned as has been done with the communication protocols.

Table II: Weighting of microcontrollers

PARAMETER	WEIGHT	PIC	Arduino	AT90CAN
Simplicity	25%	5	10	**6**
Availability of reusable code	25%	8	10	**6**
Support for necessary communication protocols	50%	8	6	**10**
Globally	**100%**	**7,25**	**8**	**7,5**

C. Selection of the Solution

It is therefore concluded that the best option is the Arduino microcontroller family. Mainly, because it has the necessary protocols to implement the system without the need to add other integrated circuits or devices. In addition, both AT90CAN and Arduino, both families can be programmed in similar languages still possible to port code from one platform to another in a relatively simple manner.

VI. Batteries

A. Alternatives

The *theoretical* or *rated* capacity of a battery is the total amount of charge, in Ah (Ampere-hours), which can be withdrawn from a fully charged battery. Sometimes, this parameter is referred to as C_n, which is the capacity at a particular discharge rate or current such the battery is depleted in n hours [25]. This means that, if the discharge current is C_n/n, then the charge released is C_n. This current is named nominal discharge current.

The charge that a battery can release depends basically on the discharge current [26]-[28] and is named *usable capacity*, C_u. The higher the discharge current, the lower the usable capacity. The Peukert equation [1] presents this dependence:

$$C_u = cI^b \qquad (1)$$

where I is the discharge current, while a and b, $b<0$, are constants that can be obtained by experiments.

The usable capacity depends also on the temperature, age of the battery, previous discharge or charge [3].

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:

Table III: Characteristics of each type of stacks

	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

B. 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.

C. 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.

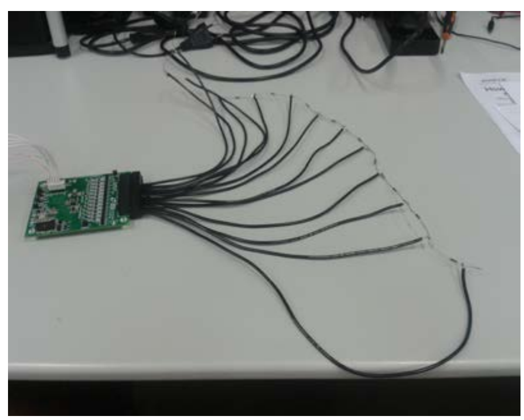

Fig.1: Resistor ladder

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.

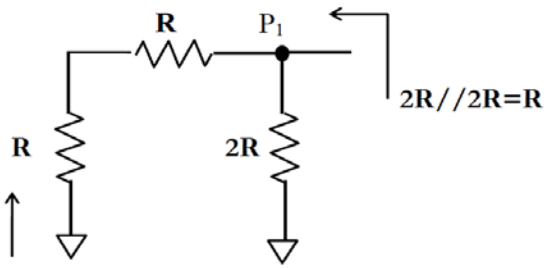

Fig.2: Diagram of a resistor ladder

VII. 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.

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