DEVELOPMENT AND EVALUATION OF A BATTERY MANAGEMENT SYSTEM (BMS) FOR SMALL AUTONOMOUS PV SYSTEMS

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ABSTRACT: The design, development and evaluation of a Battery Management System (BMS), for use in small autonomous PV systems is presented in this paper. The main functions of the BMS include charge control, overcharge protection, cell equalisation, under-discharge protection and short-circuit protection. The BMS was designed for outdoor operation and features programmable characteristics and external visual indication of system status. The BMS was designed for use with the Tadiran Li-Me AA size battery type with nominal values 800mAh capacity, 3.00V voltage, 250mA discharge current and 2.00V end of discharge voltage. The expected solar power input of a typical PV/ Li-Me battery based system is in the range 1Wp to 5Wp. The development phases of the advanced BMS included laboratory prototype design, construction and testing. The final firmware development included features like variable current charging and battery de-passivation. Five BMS units were constructed and the performance was evaluated outdoors in three different test sites. The cost of 30Euro for the final product was achieved. The evaluation results show that advanced battery control has been achieved and the system operates satisfactorily.
Keywords: Battery Storage and Control – 1: Devices – 2: Stand-alone PV Systems – 3

1. INTRODUCTION

The design, development and evaluation of an advanced Battery Management System (BMS), for use with Li-Me type rechargeable batteries in small stand-alone PV systems is presented in this paper. The work was based on the research activities undertaken in the project entitled, *"ADBATSOL – Test & optimisation of ADvanced BATteries for SOLar PV applications and development of BMS for these batteries"*. The ADBATSOL project was co-funded by the EC under the JOULE III Programme, contract No JOR3-CT98-0305.

The major part of the work for the development of the advanced BMS was undertaken at CRES, while outdoor testing of a number of prototype units was also done at ZSW and WINSOL, Italy. The Li-Me batteries were provided by TADIRAN, Israel. These institutions consisted the consortium of the ADBATSOL project.

2. TECHNICAL SPECIFICATIONS

2.1 System Level

The technical specifications on the system level refer to a PV/ Li-Me battery system with input power from the PV module in the range 1Wp to 5Wp. The Tadiran INCHARGE AA size Li-Me battery has nominal values 800mAh capacity, 3.00V voltage, 250mA discharge current and 2.00V end of discharge voltage. For temperatures below 25^0C the nominal charge rate is 80mA up to 3.40V, while for higher temperatures, end of charge should be limited to 3.30V. The maximum charge rate is 250mA to 3.45V. As of the system design, 1Wp of PV corresponds to approximately 10Wh battery storage. The system nominal voltage is 12Vdc. This is achieved by connecting 4 battery cells in series (1 string). The capacity of the system is increased by connecting up to 5 strings in parallel, thus storage capacity varies between 0.8Ah to 4.0Ah, depending on number of strings. For example, for 5 battery strings, i.e. 20 Li-Me batteries, a typical load can be between 10W and 12W.

2.2 Advanced BMS

Baring in mind these design specifications, the crucial configuration features of the advanced BMS were,

- Designed for use with Li-Me rechargeable batteries, size AA, particularly the Tadiran INCHARGE cell.
- Compact design, possible to integrate at the back surface of a small PV module.
- Low cost, i.e. up to 30Euro for the final industrial product.
- Advanced control of the battery pack, i.e. individual cell voltage detection and equalisation.
- Extremely low consumption.

The main functions of the BMS include charge control, overcharge protection, cell equalisation, under-discharge protection, short-circuit protection, outdoor operation, programmable characteristics via a PC and external visual indication of system status. Incorporation of laboratory-derived characteristics of the particular Li-Me batteries used is possible. These functions are performed by a microcontroller that operates at a clock frequency of less than 1MHz. The specifications overview of the so-called high-level BMS are summarised in Table 1 below.

Table 1. BMS specifications, system level

Current Consumption:	operating, 2mA max. standby, <1μA per cell.
Battery Voltage:	12.00V nominal. 13.60V maximum. 8.00V minimum.
Number of strings:	1 to 6
Number of cells per string:	4
Min. output voltage (to load):	6V
Maximum load:	12W

To simplify the system, the cells are grouped in parallel pairs. The battery system consists of three columns. Each column can have 4 cells in series or 4 pairs of cells in series. This scheme allows for the accommodation of 4 to 24 cells in every practical combination. In addition, failure of any cell will result in reducing the storage capacity instead of rendering the system useless.

Thus, the advanced BMS comprises of:

- 13 voltage monitoring points.
- 12 bypass circuits.
- 3 controlled current sources (charging current 0mA to 480mA in 16 steps).
- Load switch.
- Dump load switch.
- Microcontroller with A/D converter and Multiplexer.

The final design of the BMS circuit is proposed as shown in the schematic of Figure 1, see next page. The main advantage of the proposed circuit is its relative simplicity in the monitoring and equalisation control requirements of the battery cells combined with the increased system reliability in case that some battery cells fail during operation.

2.3 BMS Operation

At first, the system will be in sleep mode. When a charge condition is sensed via the INT line the MPU will awake and start monitoring cell voltage, load current and PV voltage. Cells exceeding maximum voltage will be bypassed. Charging current depends on the output of the solar module. A flashing LED indicates status.

At very low load currents the system will connect a dump load for short intervals to depassivate cells. When battery voltage falls below 8V, the system will return to sleep mode until a charge condition is sensed.

Operating parameters are stored in RAM and could be changed by connecting through an RS232 port. Loss of parameters will cause the system to return to its default settings.

2.4 BMS Hardware Construction

The final BMS prototype with batteries installed is shown in Figure 2.

Figure 2. Final high-level BMS hardware

3. ADVANCED BMS PRODUCT COST

A breakdown of the high-level BMS product cost in lots of 1000s is presented in Table 2.

Table 2. Advanced BMS production cost

Item	Cost, [Euro]
MPU (w/resonator):	6.0
Multiplexers:	5.0
Bypass circuits (12×0.7):	8.4
Controlled current sources (3×0.7):	2.1
Dump load switch:	0.5
Load switch:	0.5
Voltage Regulator:	1.0
Temperature sensor:	1.0
LED, etc:	0.5
PCB:	5.0
Total Estimated Cost:	**30.0**

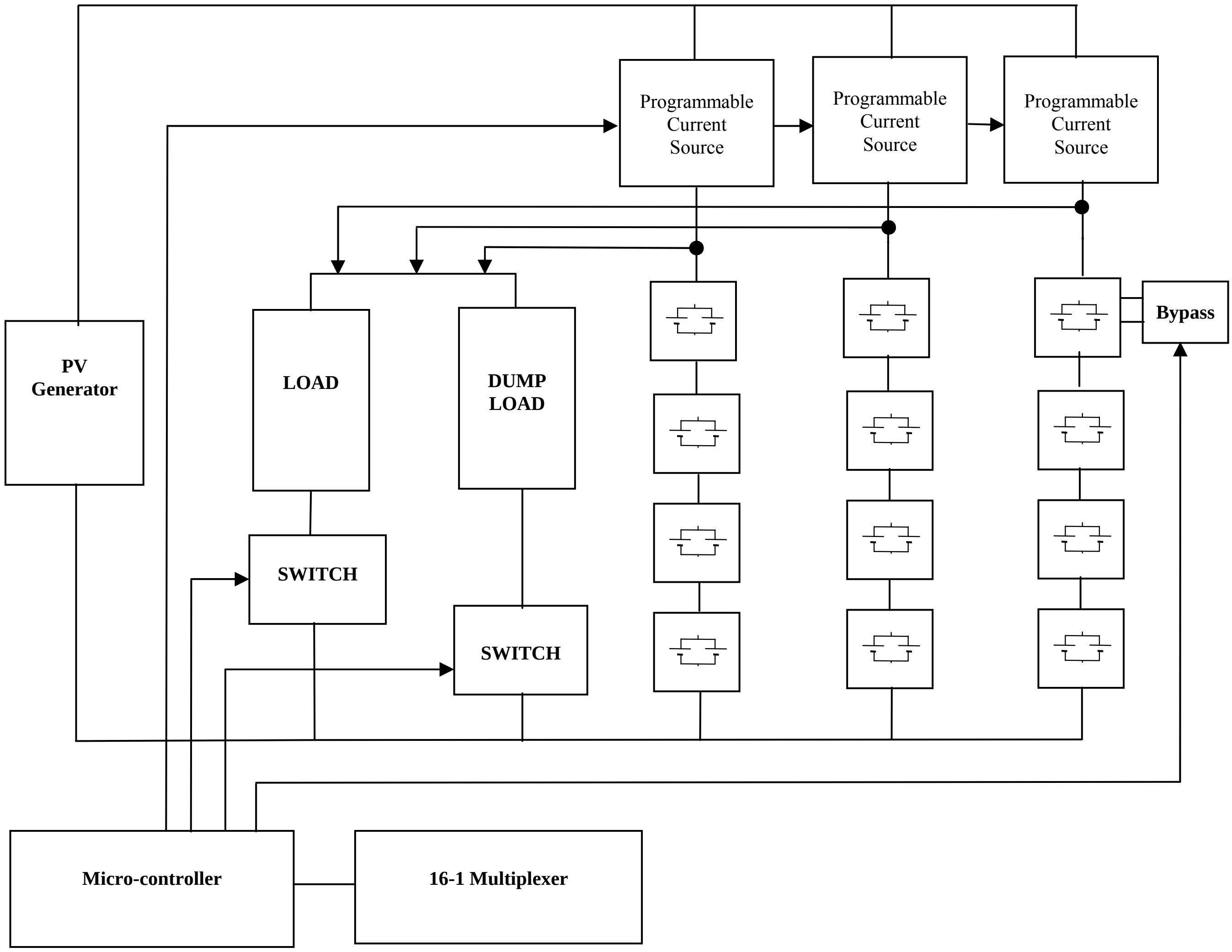

Figure 1. Final design of the BMS circuit

4. TESTING SET-UP AND BMS EVALUATION

An outdoor testing facility was designed and installed at CRES for the evaluation of a BMS unit under real operating conditions. The installation assembly comprises the main items presented in Table 3 below.

Table 3. Outdoor testing facility at CRES for the BMS evaluation

Item	Brief Description	Type
Power Supply	10Wp monocrystalline PV module	SIEMENS SP-10
Battery Storage	20 batteries, 800mAh nominal capacity each, 12Vdc system voltage, 4.0Ah system capacity	TADIRAN Li-Me
Load	5W nominal fluorescent lamp	OSRAM
Charge Control	BMS, Battery Management System	Prototype
Load Control	24h motor driven timer, adjustable every 30min	RS Components
Data Logger	Data measurement and downloading	Stylitis–100
Sensors	Irradiance	ESTI sensor
	Battery temperature	PT–100
	Battery voltage	
	PV module voltage	

4.1 Test Results

The facility was installed in September 2000 at CRES and first measurements were available in November 2000. Figure 3 shows parts of the outdoor testing facility.

A 5W load was switched on at night hours for 2 hours, i.e. 10Wh daily load. This corresponds to approximately 20% DOD for the installed battery bank of 48Wh total capacity. The batteries were recharged in the daytime from the PV generator through the BMS. The data logger was configured to measure in 10-minute intervals the voltage of each battery relative to the ground, the temperature at the interior of the BMS, the PV module voltage, the solar irradiance and the PV cell temperature.

A typical week of operation of the PV/BMS system is presented in Figure 4.

Figure 3. BMS set-up at CRES and data logger enclosure

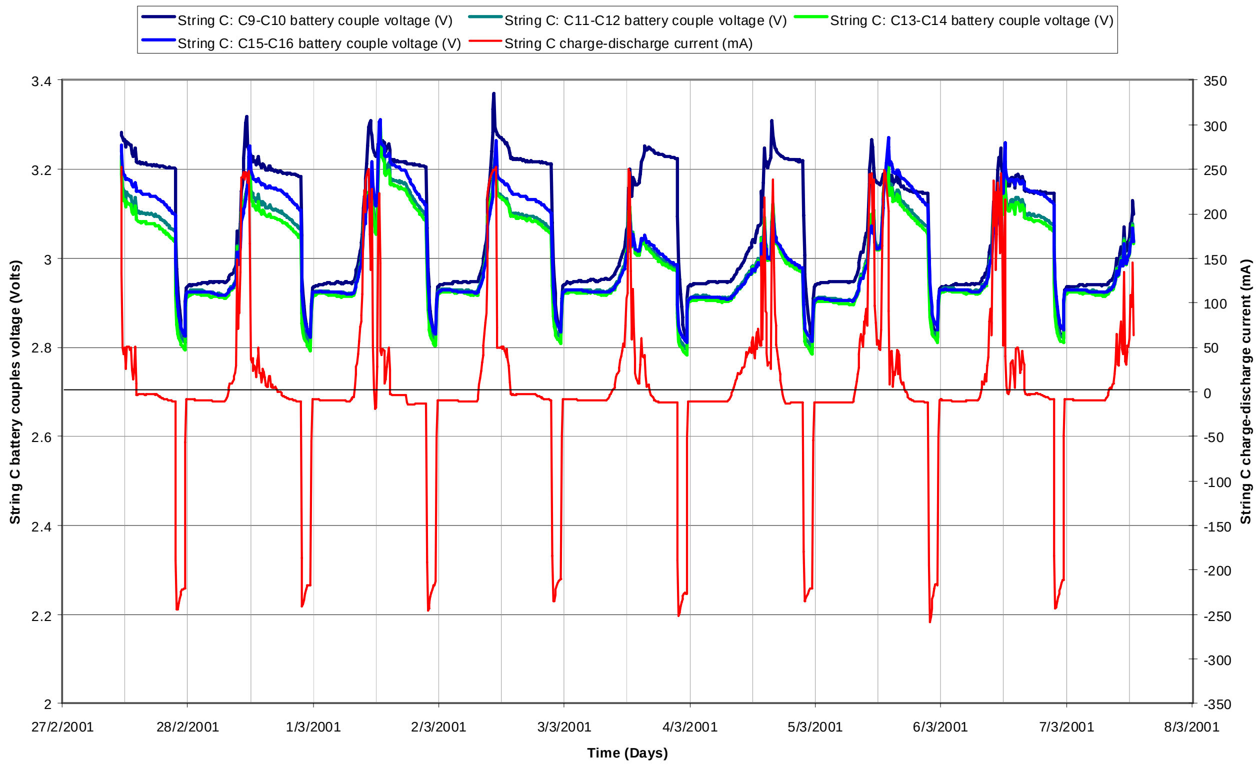

Figure 4. System operation under realistic conditions

As it is seen in Figure 4, adequate battery control has been achieved and the system operates satisfactorily.

5. CONCLUSIONS

The development of a Battery Management System for advance control of Li-Me batteries in small stand-alone PV systems was presented in this paper. The BMS incorporates functions such as charge control, overcharge protection, cell equalisation, under-discharge protection and short-circuit protection, variable current charging and battery cell depassivation. The development phases of the advanced BMS included laboratory prototype design, construction and testing. The overall cost of the final product was kept at 30Euro.

A BMS unit was evaluated outdoors at CRES. The results showed that the system operates satisfactorily and the specification targets have been achieved.