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Solar-Based Battery Management System (BMS) And SOC Development

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Abstract

The safety, efficiency, and longevity of batteries which are the most common with solar panels require a battery management system (BMS). Among the key functions of the BMS is to measure the State of Charge (SOC) of the battery which is a measure of the energy left in the battery. It is the exact value of SOC that prevents overcharging or over discharging of the battery. Furthermore, the research shows that BMS installations must have the necessary protective measures to avoid such a situation as the excess flow of current into the battery. To make the BMS retrieve the battery status, communication modes such as the ZigBee can be used which are not only simple but also very reliable. The BMSs in the complicated arrangements like plug-in hybrid cars also have the responsibility of temperature control, health, and power management in addition to other responsibilities. The role of the BMS in a hybrid electric vehicle (HEV) is even greater because the BMS must control the energy flow among the battery, the engine, and the other components. Moreover, the BMS should accept solar radiation, and do the charging in the most convenient and fast manner in case photovoltaic panels are integrated. This is because BMS, solar panels and accurate SOC reading all assist in making hybrid cars safe, reliable, and energy saving, ultimately. When solar panels are fed to the BMS, the management of a solar energy and charging of the battery is properly handled by the management system. Concisely, effective work of a properly functioning BMS along with the application of solar technology and precise recording of SOC makes the system safer, more reliable and with reduced energy consumption.

Keywords: Arduino Uno, Battery, Battery Management System (BMS), Hybrid Electric Vehicle (HEV), Solar Panel

INTRODUCTION

A Battery Management System (BMS) is literally the nervous system of the battery pack that monitors, protects, and commands the battery to ensure it is functioning in a variety of load and environmental conditions. It performs several significant functions such as the State of Charge (SOC) estimation, State of Health (SOH) estimation, thermal control, voltage balancing, fault detection, and communication with the vehicle subsystems. The most important one is the SOC estimation to the large majority because this provides the amount of energy that will be left in the battery. The accurate value of SOC enables one to distribute power more efficiently, prevent overcharging and deep discharging of the battery and, therefore, increases the battery lifetime. Another component that would make the concept of BMS comprehensive is security. Lithium-ion batteries, that are very common in HEVs due to their high energy density and long cycle life, can be spoiled when they are put under circumstances like excessive current,

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excessive heat, and excessive voltage. Accordingly, in the present day, BMS designs are loaded with an abundance of protection mechanisms to track abnormal cases and cause the respective responses. This may be switching off the battery by relays, decreasing the current of charge/discharge, or, still, the turn-on of the cooling appliances [1]. Through this, safety mechanisms will ensure that the battery is operating within its safety limits and that it excludes hazardous events such as thermal runaway. Other than safety and monitoring, communication is also crucial to the BMS internal processes. The majority of the current units are using technologies such as Controller Area Network (CAN) and wireless solutions, such as the ZigBee, in transmitting battery data to the various components of the vehicle. By allowing the use of real-time monitoring, system robustness, and including the collective functionality of multiple battery modules in extensive energy storage systems, these communication loops work [2].

The very integration of solar panels and systems in hybrid vehicles has, in the recent past, become the subject of discussion as one way of further reducing the consumption of fuel and encouraging the use of eco-friendly systems. Solar panels can receive renewable energy and serve as a source of additional power to the battery especially in the times when parking or at times of low loads et.al. In solar conditions, BMS is obliged to monitor the charging process to prevent overcharging as well as to use the collected energy in the most effective manner. This combination does not only increase the range of distance which can be covered but also reduces the dependence on the outside charging stations or fuel. The bottom line is that the combination of BMS technology, accurate SOC measurement and solar-assisted energy harvesting would enable a more efficient and cleaner system of hybrid electric vehicle. With the effort and capital still being invested in research in areas such as battery modeling, wireless BMS, and integration of renewable energy, BMS development will be the factor that deepens the performance, safety, and eco-friendliness of the future hybrid and electric vehicles. This general is the foreword to the detailed analysis of the BMS, SOC estimation, and the use of solar energy as the critical components of the new generation hybrid transportation systems [3–7].

LITERATURE REVIEW

BMS and SOC Development for Electric Vehicles

The development of a Battery Management System (BMS) and State of Charge (SoC) in Electric Vehicles would entail designing intelligent control systems that would monitor, protect, and improve the work of EV battery packs. The BMS is involved with the control of the voltage, current, power, and cell balancing to maintain the operation cost effective and safe. The improvement of the SoC largely concerns the provision of the most accurate estimation of the remaining battery charge through the implementation of the algorithm, including the use of the Kalman filters, using coulomb counting, or machine learning. With BMS and SoC estimation we can have improved range estimation, battery life, high charge speed, elimination of thermal problems, and overall reliability of electric cars [8–11].

BMS Development and Industrial Standards

The development of BMS and Industrial Standards is primarily focused on producing safe and reliable Battery Management Systems which could be employed in multiple applications with wide areas of usage such as solar energy storage, UPS, telecom backup, and portable power systems. The BMS design involves the development of voltage, current, and temperature sensing circuits; cell balancing (active or passive); protection functionality; and development of State-of-Charge (SOC) and State-of-Health (SOH) estimation algorithms. The industrial standards exist as a measure of ensuring the battery packs are safe during varied environment and use conditions. The IEC 62133 standard on the safety of rechargeable batteries, the UN 38.3 standard on the transport certification, the IEC 61508 standard on functional safety, and the IEC 62619 standard on the industrial lithium battery systems are the most essential standards [12].

These standardization covers the electrical protection requirements, mechanical strength, thermal behavior, the vibration testing and the fault handling. Following these rules, BMS-powered battery systems can guarantee safety, efficiency, and a long-term existence and also address the demanded standards in the industrial and renewable energy spheres [13].

CORE BMS FUNCTIONS IN SOLAR SYSTEMS

Energy Harvesting and MPPT Integration

PV-BMS system typically has MPPT controllers or can be configured to use MPPT convertors to get the maximum power that can be extracted and still keep the battery within its safe operating range (such as not permitting excessively high charging current or charging at an inopportune moment when the cell was hot). Literature has also covered a lot of experimental research studies in which MPPT control is combined with BMS charge-control logic to enable it to have greater variance between the variability of PV generation and battery acceptance characteristics [14].

SOC and SOH Estimation

Optimization. Classical coulomb-counting and open-circuit voltage (OCV) methods are usually supplemented with Kalman filters, extended Kalman filters (EKF), and lately machine learning techniques to manage nonlinear battery behavior and to take into account uncertainties due to PV intermittency. Surveys Precise SOC and SOH determination serve as the basis for the correct implementation of the charge/discharge cycles and the as well as the lifetime journal of the research community, which considers that better state estimation under real PV charging profiles is still an open problem [15].

Cell Balancing and Pack Health

Both passive and active balancing methods have been deeply analyzed, and review articles made recently indicate that active cell balancing would be the most suitable option for battery packs used in photovoltaic systems with a long lifespan, even if it entails higher complexity and cost. Properly functioning balancing algorithms become particularly significant in situations where photovoltaic systems are charging in an unbalanced manner (partial sun, shading). Imbalance in cells (divergence of voltage and capacity in cells) negatively affects the available capacity and may also speed up the process of degradation [16].

EXPERIMENTAL SETUP (BMS & SOLAR PANEL)

- *Batteries:* 12V 8Ah Li-ion and 12V 8Ah Lead-Acid
- *Solar Panel:* 12V, 20W with MPPT charge controller
- MPPT (Maximum Power Point Tracking)
- Cell balancing (Li-ion only)
- *Load Conditions:* Constant resistive load (e.g., 10W) to simulate device/vehicle consumption
- *Measurement Parameters:* Voltage, current, SOC, charge/discharge efficiency.

Types of Battery Testing

- Lead-Acid Battery
- Li-ion Battery

Lead-Acid Battery: A 12V 8Ah lead-acid battery is a storage unit that combines lead plates and sulfuric acid to store energy.

12V (12 volts) is the battery's nominal voltage, which means that the battery can give a continuous output of approximately 12 volts.

8Ah (8 ampere-hours) is the capacity of the battery that indicates the battery can supply 8 amps of a current for 1 hour or 1 amp for 8 hours before the battery is completely discharged.

Li-ion Battery: A 12V 8Ah lithium-ion (Li-ion) battery is a unit that can be recharged and uses lithium-based chemical cells to store electrical energy.

12V (12 volts) is the nominal voltage of the battery pack, which is usually a result of connecting three or four Li-ion cells in series.

8Ah (8 ampere-hours) is a measure of the battery's capacity, and it is the equivalent of supplying 8 amps of current for 1 hour, 1 amp for 8 hours, or any similar combination of time and current before the battery is fully discharged.

Still, Li-ion batteries need a Battery Management System (BMS) to guard them against overcharging, over-discharging, overheating, and short circuits.

Solar Panel

A 20-Watt solar panel is a small solar-powered unit that offers a limited but steady power output for energy-saving devices. Most often, it includes either mono-crystalline or poly-crystalline cells of high efficiency, which are sealed inside a metal-framed glass panel. The panel delivers around 17–18 volts of open circuit voltage and 1.1–1.2A of current under standard test conditions, thus making it a device that can be used for a small battery charging, power supply of sensors purposes, LED lamps, IoT gadgets, and portable systems [17]. Because of its light and strong construction, a 20-Watt panel is popularly employed in off-grid systems, solar kits, and hobby electronics. It remains stable in outdoor conditions and is, therefore, an excellent renewable energy source for small-scale loads.

MPPT

The key component to a solar panel-based Battery Management System (BMS) is Maximum Power Point Tracking (MPPT) to ensure the flow of energy into the PV module and to ensure efficient and safe charge of the battery. The solar panels are designed to operate at various voltages and currents based on the sunrays and temperature and when the panel is shaded or not. MPPT is always able to relocate the operating point of the panel to achieve the highest amount of power that is available therefore no power would go to waste when the light is low or the condition that varies. The MPPT controller resembles a companion to the BMS: it regulates the voltage and current charged to the battery, protects the battery against overcharging and maintains constant charging curves to lithium or lead-acid batteries [18].

Arduino Uno

The Arduino Uno, being the brain of the solar-powered Battery Management System, is the one that addresses all data acquisition, processing, and control tasks needed in a safe and efficient functioning of the battery. It measures the voltage on the analog inputs using voltage dividers, measures the current using a sensor like the ACS712 or INA219, and measures the temperature using a thermistor or the DS18B20 to avoid overheating of the battery. The Arduino on the basis of this knowledge controls the on and off of the charge and discharge with a MOSFET or relay as well as is capable of controlling the solar input either by PWM or by simple MPPT algorithms. It also performs State of Charge estimation by using techniques such as the voltage-based analysis or coulomb counting. Moreover, Arduino Uno is a device that monitors the system and can be attached to a display or relay some information via a serial or wireless module. It is a useful device to use as a prototype BMS in a solar energy application due to its programmability, low cost and robustness.

METHODOLOGY OF BATTERY-MANAGEMENT SYSTEM

A design and evaluation of a Battery Management System (BMS) with battery charging by the solar panel on a Hybrid Electric Vehicle (HEV) has a methodology that outlines a line of carefully thought-out steps. These procedures ensure that the system has been engineered, simulated, actualized, and tested in a dependable and well-organized manner. The whole design process is divided into five major stages, which are system design, modeling, and simulation, hardware development, software, and control implementation, and performance evaluation [19].

System Design and Requirement Analysis

The first stage focuses on identifying the functional and technical requirements of the BMS and its integration with the HEV's electrical system in figures 1 and 2.

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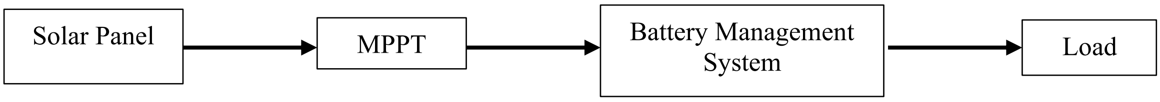

Figure 1. Layout of battery management system.

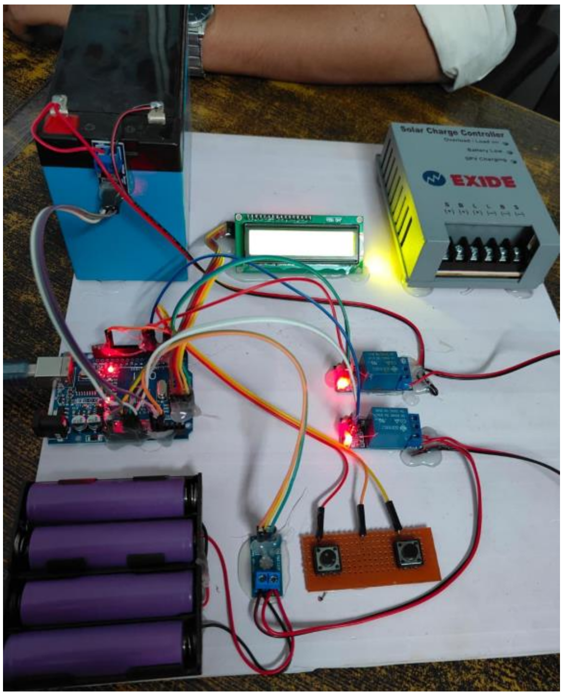

Figure 2. Hardware implementation.

Key activities include Choosing battery parameters like the chemical type (for example: Li-ion), capacity, nominal voltage, and allowable operating range.

Specifying the BMS functionalities to be implemented, including SOC estimation, cell balancing, overcurrent protection, temperature monitoring, and communication protocols (CAN, ZigBee).

Identifying the solar panel characteristics, maximum power point (MPP) range, and the anticipated energy contribution.

- *Battery Modeling:* The battery is modeled using an equivalent circuit model (ECM) or a mathematical model describing voltage, current, and temperature behavior.
- *SOC Estimation Model:* The chosen algorithm is tested under various load conditions to verify accuracy.
- *Solar Charging Model:* A solar panel model is created using I–V characteristics.
- *Hardware Development:* After simulation, hardware components are developed and assembled based on the design.
- *BMS Hardware:* Current sensors, voltage sensors, and temperature sensors are selected. Overcurrent and overvoltage protection circuits are designed using relays, or switches.
- *Microcontroller:* A microcontroller such as Arduino, is chosen to run SOC algorithms and control logic.

Solar Charging Unit

Solar panels are selected based on required power output.

A charge controller equipped with MPPT functionality is developed.

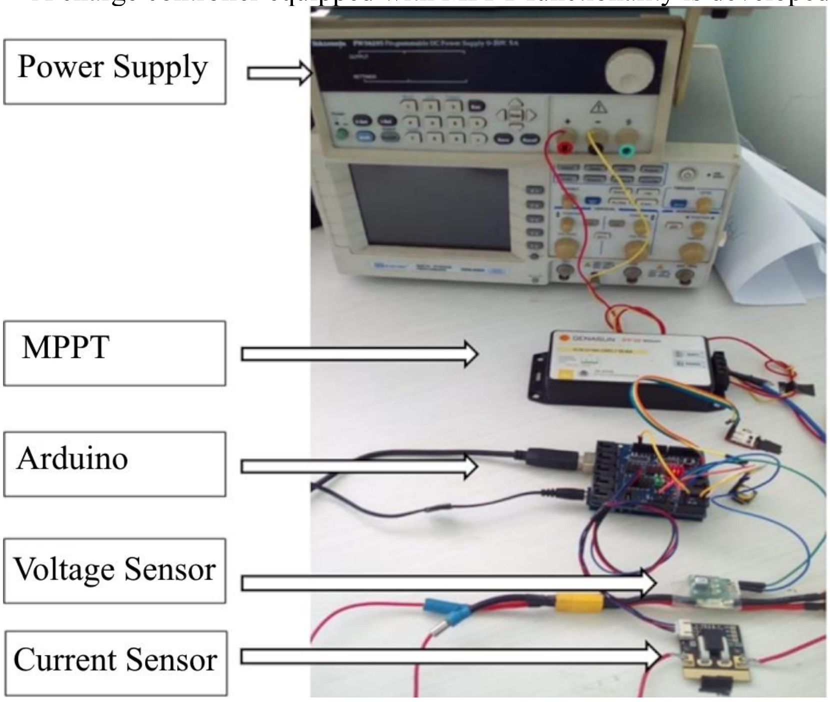

Figure 3. Testing platform of used equipment in BMS.

The detailed stages method used here lessens the chances of overlooking any part of the project while creating an efficient BMS system which includes solar charging and SOC estimation integration for Hybrid Electric vehicles in figure 3.. It is a sequential manner of working the final safety, accuracy, and energy-saving feature of the system in HEV application through device design & simulation, hardware implementation, and testing [20].

CONCLUSION

Proper estimation of the State of Charge (SOC) of a solar-powered Battery Management System (BMS) is critical towards maintaining an efficient, reliable, and long service life solar-powered energy storage system. The BMS is the device that can ensure that the batteries are running within safe parameters as the same batteries can be used to work under different conditions of solar generation. The SOC further assist the system in making it more operational through being able to predict energy consumption correctly, optimization of charge-discharge, and load balancing. The combination of these technologies is the one that has permitted the possibility to have a stable energy supply, the reduction of energy losses and the use of solar resources in a still viable way. There will be the need to use advanced BMS and SOC techniques to come up with energy systems which are resilient, scalable, and cost effective as use of solar energy will keep on rising.

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