

Practical Installation of a Battery Management System with V2X Capability

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Abstract - This paper presents an experimental demonstration of a basic bidirectional energy transfer consistent with the Vehicle-to-Everything (V2X) concept, using a commercial Battery Management System (BMS) not originally intended for automotive applications. A 14-series (14S) lithium-ion battery pack integrated with a 48 V BMS and a bidirectional inverter is experimentally evaluated under low-power operating conditions. The study focuses on practical system integration, protection behavior, and cell balancing functionality using minimal laboratory equipment. The results show that essential BMS functions are sufficient to support controlled bidirectional energy flow at low power levels, highlighting both the feasibility and limitations of low-cost BMS-based V2X experimental setups.

Cuvinte cheie: baterie, sistem de management al bateriei (BMS), vehicul electric (EV), capacitate V2X.

Keywords: battery, battery management system (BMS), electric vehicle (EV), V2X capability.

I. INTRODUCTION

Battery Management Systems (BMS) are essential components for the safe and reliable operation of lithium-ion battery packs in electric vehicles (EVs), stationary storage systems, and other energy-related applications. Their primary role is to ensure that battery cells operate within predefined electrical and thermal limits by continuously monitoring cell voltages, current, temperature, and state of charge (SOC), while implementing protection and balancing mechanisms to prevent degradation or hazardous conditions [1]-[3]. Advanced BMS architecture also includes model-based estimation algorithms and diagnostic functions [4], [20].

Traditionally, BMS architectures are designed to support unidirectional energy flow, where the battery pack is charged from an external source and discharged to supply a dedicated load. In this context, the BMS mainly functions as a supervisory and protective unit, without actively participating in energy exchange control beyond enforcing safety constraints [5]. However, the increasing penetration of electric vehicles and distributed energy resources has accelerated interest in bidirectional energy transfer concepts, commonly referred to as Vehicle-to-Everything (V2X). V2X encompasses Vehicle-to-Grid (V2G), Vehicle-to-Home (V2H), and Vehicle-to-Load (V2L) interactions, enabling batteries to act as temporary energy storage units capable of supplying external loads or the electrical grid [6], [7]. The economic and grid-support potential of

V2G systems has been extensively analyzed in the literature [8].

In conventional automotive implementations, V2X functionality relies on advanced power electronics, dedicated communication protocols, and grid-compliant control strategies, typically integrated into the vehicle's onboard charger and energy management system [4]. Such systems are complex, costly, and tightly coupled with manufacturer-specific hardware and software platforms. Consequently, experimental access to V2X functionality is often limited, particularly in academic or educational environments.

From a theoretical perspective, the feasibility of bidirectional energy flow is primarily governed by the capability of the power conversion stage and the BMS to maintain safe operating conditions during both charging and discharging processes. While the inverter or bidirectional converter determines the direction and quality of energy transfer, the BMS remains responsible for enforcing voltage limits, current constraints, and cell balancing requirements [5], [9]. Even in the absence of grid-synchronized control or communication layers, a BMS that ensures stable and balanced operation of a battery pack can enable a basic form of bidirectional energy utilization, particularly at low power levels.

In this context, the present work investigates the use of a commercial 14S, 48 V BMS, originally intended for light electric mobility applications such as electric scooters, in a simplified experimental configuration aimed at demonstrating fundamental V2X principles. The BMS is integrated with a 14-cell lithium-ion (18650) battery pack and a commercially available bidirectional inverter, forming a laboratory-scale system capable of charging the battery pack and subsequently supplying an external AC load of up to 100 W. Unlike full-scale automotive V2X systems, the proposed setup does not implement grid interaction, communication protocols, or active power control strategies. Instead, it focuses on the physical feasibility of bidirectional energy transfer under the supervision of a standard BMS.

The main objective of this study is to experimentally assess the role of essential BMS functions (cell voltage monitoring, protection mechanisms, SOC supervision, and cell balancing) in supporting controlled bidirectional operation using accessible and low-cost components. By emphasizing practical system integration and real operating conditions, this work aims to bridge the gap between theoretical V2X concepts and simplified experimental validation platforms.

Having established the theoretical background and motivation for employing a non-automotive BMS in a bidirectional energy flow scenario, the following sections present the materials, methods, and experimental setup in detail, followed by an analysis of the observed system behavior and limitations.

II. MATERIALS, METHODS AND SCHEMATICS OF THE PRACTICAL INSTALLATION

A. System Architecture and Practical Implementation

The overall electrical configuration of the experimental setup, including the battery pack, Battery Management System (BMS), inverter, and protection elements, is illustrated in Figure 1.

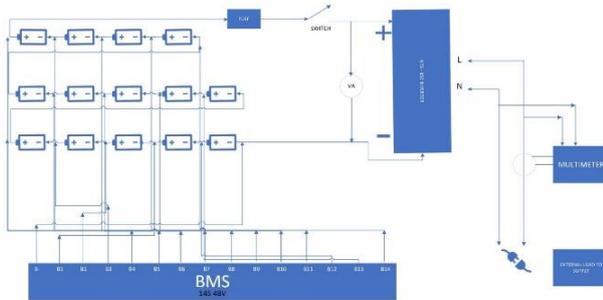


Fig. 1. Electrical wiring diagram of the practical installation.

Figure 1 illustrates the electrical wiring diagram of the proposed experimental setup, which represents a laboratory-scale implementation of a bidirectional energy transfer system supervised by a Battery Management System (BMS). The schematic provides a detailed representation of the electrical interconnections between the battery pack, the BMS, the inverter, and the external load, emphasizing the practical realization of the system under real operating conditions.

The core of the installation consists of a 14-series (14S) lithium-ion battery pack, assembled from individual 18650 cells and connected to a commercial 48 V BMS. Each cell connection is routed to the BMS through dedicated sense wires, enabling continuous monitoring of individual cell voltages. This configuration allows the BMS to detect voltage imbalances and activate the internal balancing circuitry when predefined thresholds are exceeded. The BMS is connected in series with the battery pack on both the charging and discharging paths, ensuring that all current flowing into or out of the battery is supervised and protected.

A bidirectional inverter is interfaced with the battery pack through the BMS power terminals, enabling the conversion between direct current (DC) and alternating current (AC). In charging mode, the inverter operates as an AC–DC converter, supplying controlled DC power to charge the battery pack. In discharging mode, the inverter converts the DC energy stored in the battery into AC power to supply an external load. The inverter selection was based on compatibility with the nominal 48 V battery voltage and the availability of integrated protection feature relevant for experimental validation.

To ensure operational safety and facilitate experimental observation, additional protective and measurement components were incorporated into the installation. A fuse rated at 16 A was placed in series on the main DC power line supplying the inverter, providing protection against overcurrent and short-circuit conditions. A manual DC disconnect switch was also included, allowing complete electrical isolation of the inverter from the battery pack during setup, maintenance, or emergency conditions.

Electrical measurements of the battery pack voltage and current were performed using a combined voltmeter–ammeter instrument connected in series with the DC link. This instrumentation enables real-time monitoring of the charging and discharging processes, ensuring that the operating limits defined by the BMS—namely maximum charging voltage and minimum discharge voltage—are not exceeded. On the AC side, the inverter output is provided through a standard Schuko socket, allowing the connection of common household loads. For experimental evaluation, a low-power load was selected to ensure operation within the safe current limits of both the inverter and the BMS.

The schematic shown in Figure 1 bridges the gap between theoretical V2X concepts and their practical realization by illustrating a simplified but functional configuration. While the setup does not include grid synchronization, communication interfaces, or advanced energy management algorithms, it captures the essential elements required for controlled bidirectional energy transfer. This approach enables a clear assessment of the role played by the BMS in supervising battery operation during both charging and discharging phases.

The experimental methodology adopted in this work focuses on repeatable charge–discharge cycles performed under controlled conditions. During each test, the battery pack is charged up to the maximum allowable voltage defined by the BMS and subsequently discharged by supplying an external AC load until the minimum voltage threshold is reached. This procedure allows direct observation of BMS protection behavior, inverter operation, and cell balancing activity, providing a consistent basis for the analysis presented in the following sections.

B. Experimental Procedure

The experimental evaluation was carried out through controlled charge–discharge cycles to assess the behavior of the Battery Management System (BMS), the inverter, and the battery pack during bidirectional energy transfer. All tests were performed under laboratory conditions, with operating parameters selected within the nominal limits specified by the equipment manufacturers.

Prior to testing, the battery pack connections and BMS sense wiring were verified, and the initial state of charge (SOC) of the individual cells was assessed by measuring their open-circuit voltages. The charging process was performed using the inverter operating in AC–DC mode, while the battery voltage and current were continuously monitored. Charging was terminated when the total pack voltage reached 58.8 V, corresponding to 4.2 V per cell in the 14S configuration.

Subsequently, the system was operated in discharging mode by supplying a low-power AC load of approximate-

ly 45 W through the inverter in DC–AC conversion mode. The discharge process was stopped when the battery voltage decreased to the minimum allowable limit of 44.8 V (3.2 V per cell). During both operating modes, the activation of BMS protection and cell balancing functions was monitored through voltage and current measurements. The experiments were repeated under identical conditions to ensure repeatability, and the recorded data were used for the analysis presented in the following sections

III. EQUIPMENT USED IN ASSEMBLY

A. Battery pack

The experimental setup employs a lithium-ion battery pack assembled from cylindrical 18650 cells, a widely used cell format in energy storage and electric mobility applications due to its favorable energy density, availability, and cost-effectiveness [2]– [10]. The 18650 cells have standardized mechanical dimensions of 18 mm in diameter and 65 mm in height, which facilitates modular pack assembly and reproducibility of experimental configurations. However, lithium-ion chemistry imposes strict safety constraints regarding voltage and temperature limits [11].

The battery pack used in this work consists of 14 lithium-ion cells connected in series (14S configuration), resulting in a nominal voltage compatible with the selected 48 V Battery Management System (BMS). The individual cells are of type 18650C, manufactured by YDJW, with a nominal energy rating of 9.25 Wh per cell. The main electrical and thermal characteristics of the employed cells are summarized in Table I.

TABLE I.
TYPICAL SPECIFICATIONS OF THE 18650 LITHIUM-ION CELLS USED IN THE BATTERY PACK

Parameter	Value
Nominal cell voltage	3.7 V
Cell capacity	2200–3500 mAh
Nominal energy	9.25 Wh
Continuous discharge rate	2C–20C
Recommended charging current	0.5C–1C
Cycle life	500–800 cycles
Operating temperature	0°C to 45°C
Cell mass	45–50 g
Cell dimensions	18 mm × 65 mm

The selection of 18650 cells is justified by their stable voltage characteristics over a wide state-of-charge (SOC) range and their suitability for low- to medium-power experimental applications. These characteristics make them appropriate for investigating controlled charge–discharge behavior under the supervision of a commercial BMS.

B. Inverter

The conversion between direct current (DC) and alternating current (AC) in the proposed setup is performed using a Mean Well NTS-450 inverter. This inverter generates a pure sinusoidal AC output and is commonly employed in off-grid, mobile, and backup power systems due to its reliability and integrated protection features [10],[13].

In the present application, the inverter serves a dual role: it enables charging of the battery pack from an AC source and, during discharging, supplies AC power to an external load. The inverter was selected based on its compatibility with the nominal 48 V battery voltage and its power rating, which significantly exceeds the low-power experimental load used in this study, ensuring operation within safe limits. The electrical characteristics and protection thresholds were verified using the manufacturer’s official technical documentation [15].

The main characteristics of the inverter relevant to the experimental setup are summarized in Table II.

TABLE II.
MAIN CHARACTERISTICS OF THE INVERTER USED IN THE EXPERIMENTAL SETUP

Parameter	Value
Inverter model	Mean Well NTS-450
Rated output power	450 W
Input voltage	48 V DC
Output voltage	230 V AC
Output waveform	Pure sine wave
Efficiency	>90% (typical)
Integrated protections	Overload, short circuit, over-temperature, low battery voltage

By operating the inverter well below its rated power, the experimental setup minimizes thermal stress and conversion losses, allowing a clearer assessment of the BMS-supervised bidirectional energy flow.

C. BMS (Battery Management System)

The battery pack is supervised by a commercial 14S, 48 V Battery Management System designed for lithium-ion battery applications. The primary function of the BMS is to ensure safe battery operation by continuously monitoring electrical parameters and enforcing protection thresholds during both charging and discharging processes.

The BMS supports cell balancing, which is essential for series-connected battery packs to reduce voltage imbalances caused by manufacturing tolerances, aging effects, or uneven load distribution. The employed BMS implements passive balancing, where excess energy from higher-voltage cells is dissipated as heat through resistive elements [5]. Compared to passive balancing, active balancing improves overall efficiency and enhances the usable capacity of the battery pack, particularly in low-power, long-duration applications. Passive balancing remains the most used method in low-cost commercial BMS implementations due to its simplicity and reliability [12].

The codification and main electrical characteristics of the employed BMS are presented in Table III.

The selected BMS operates as a supervisory and protective element rather than an active energy management controller. Nevertheless, its essential functions—cell voltage monitoring, protection enforcement, and balancing—are sufficient to support the low-power bidirectional energy transfer investigated in this work.

State-of-charge estimation methods typically rely on coulomb counting and model-based correction techniques [18].

TABLE III.
MAIN SPECIFICATIONS OF THE BATTERY MANAGEMENT SYSTEM

Parameter	Value
Cell configuration	14S
Nominal pack voltage	48 V
Maximum charging voltage	58.8 V
Minimum discharge voltage	44.8 V
Maximum continuous current	20 A
Cell balancing	Passive / Active (model-dependent)
Protection functions	Overcharge, over-discharge, over-current, short circuit, temperature
SOC estimation	Yes

IV. RESULTS AND PRACTICAL ASSEMBLY

This section presents the experimental results obtained from the practical implementation described in Section II, with emphasis on charging and discharging behavior, protection enforcement by the Battery Management System (BMS), and the observed effectiveness of cell balancing in a low-power bidirectional energy transfer scenario.

A. Practical Assembly and Initial Observations

The practical assembly of the experimental setup enabled direct observation of BMS-supervised battery operation during controlled charge–discharge cycles. Initial measurements indicated small voltage differences between individual cells within the 14S lithium-ion battery pack, attributable to manufacturing tolerances and prior usage history.

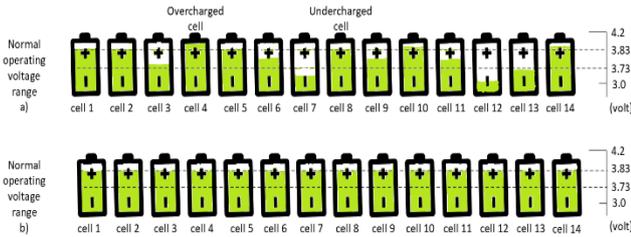


Fig. 2. Cell balancing technique.

Figure 2 provides a conceptual reference for interpreting experimental observations related to cell imbalance and subsequent voltage equalization during system operation.

B. Charging and Discharging Experimental Results

During the charging phase, the battery pack voltage increased progressively under BMS supervision until reaching the maximum allowable voltage of 58.8 V (4.2 V per cell). The charging process was terminated at this threshold, confirming correct overvoltage protection behavior. No abnormal current levels or protection-triggered interruptions were observed.

In the discharging phase, the inverter supplied a low-power external AC load rated at approximately 45 W. The battery voltage decreased smoothly until the minimum cutoff limit of 44.8 V (3.2 V per cell) was reached, at which point the discharge process was stopped in accordance with the BMS protection strategy. Deep discharge below recommended voltage thresholds significantly accelerates capacity degradation in lithium-ion cells [12].

TABLE IV.
EXPERIMENTAL CHARGING AND DISCHARGING RESULTS

Parameter	Charging phase	Discharging phase
Battery pack voltage range [V]	53.1 – 58.8	58.8 – 44.8
Average battery current [A]	2.2	0.95
Peak battery current [A]	2.8	1.1
AC load power [W]	–	45
Operating mode	AC–DC	DC–AC

The measured values indicate stable system operation well within the continuous current rating of the BMS, validating the suitability of the selected components for low-power bidirectional operation.

C. Cell Balancing Performance

Initial voltage measurements revealed a noticeable, though moderate, dispersion among the individual cell voltages within the battery pack. During successive charge–discharge cycles, the BMS automatically activated its cell balancing function, resulting in a gradual reduction of voltage differences between cells. Cell-to-cell variations significantly influence long-term performance and lifetime in automotive battery packs [21].

TABLE V.
CELL VOLTAGE DISPERSION BEFORE AND AFTER BALANCING

Operating condition	Max cell voltage [V]	Min cell voltage [V]	Voltage difference [mV]
Before balancing	4.11	4.01	100
After balancing	4.07	4.04	30
During discharge	3.46	3.42	40

The quantitative reduction in voltage dispersion confirms the effectiveness of the balancing mechanism in maintaining a more uniform state of charge across the series-connected cells.

To further contextualize these results, representative battery behavior with and without effective balancing is illustrated in Figures 3–6.

Figure 3 shows the battery pack at full charge under balanced conditions, where cell voltages are nearly uniform, confirming effective BMS supervision.

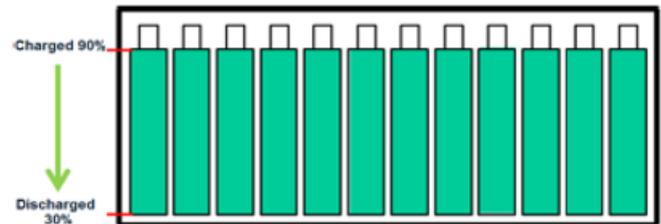


Fig 3. Battery pack at full capacity

Figure 4 illustrates a mismatched discharged pack, highlighting voltage dispersion between cells that can lead to premature cutoff and reduced usable capacity.

Figure 5 presents full discharge with active balancing enabled, demonstrating improved voltage uniformity and better energy utilization.

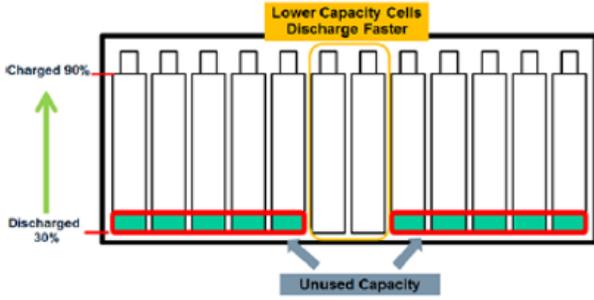


Fig 4. Mismatched discharged battery pack

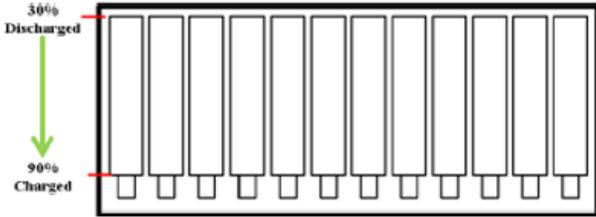


Fig 5. Full depletion with active balancing

Figure 6 depicts charging without balancing, where certain cells reach the maximum voltage limit earlier, increasing the risk of overvoltage protection activation.

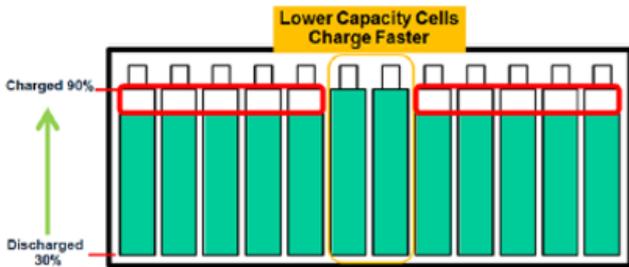


Fig 6. Charging without balancing

D. Discussion and System-Level Interpretation

The experimental observations confirm that one of the primary responsibilities of a BMS—maintaining lithium-ion cells within safe operating limits—is effectively fulfilled during both charging and discharging. This function becomes particularly relevant in bidirectional energy transfer scenarios, where repeated cycling may otherwise accelerate cell degradation. Repeated cycling associated with V2X services may increase degradation if proper voltage and thermal control is not enforced [14], [16].

Although the internal balancing algorithm of the commercial BMS used in this study is not directly accessible, the observed voltage convergence behavior is consistent with the decision-making principles illustrated in Figure 7.

To emphasize the scope and originality of the proposed setup, a comparison with conventional automotive V2X systems is presented in Table VI.

Overall, the results validate the original contribution of this work: a standard, low-cost BMS can effectively supervise controlled bidirectional energy transfer under laboratory conditions, enabling functional demonstration of fundamental V2X principles using accessible components.

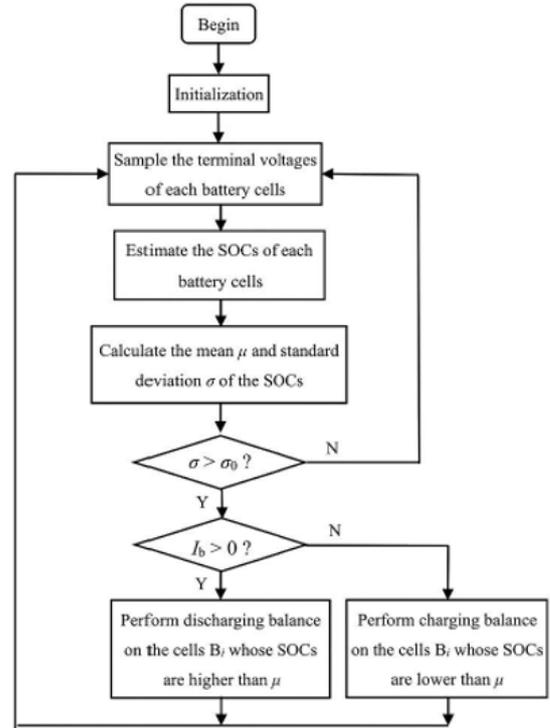


Fig. 7. Flowchart of active cell balancing method.

TABLE VI
COMPARISON BETWEEN THE PROPOSED EXPERIMENTAL SETUP AND CONVENTIONAL V2X SYSTEMS

Feature	Proposed setup	Automotive V2X systems
BMS type	Commercial, non-automotive	Automotive grade
Power level	Low (<100 W)	kW range
Grid synchronization	No	Yes
Communication protocols	No	Yes
Intended application	Experimental / educational	Grid services

Advanced prognostic approaches based on probabilistic models are increasingly used for remaining useful life prediction in lithium-ion batteries [19].

V. CONCLUSIONS

This paper presented an experimental validation of a simplified bidirectional energy transfer setup supervised by a commercial Battery Management System (BMS) not originally intended for automotive applications. A 14-series lithium-ion battery pack integrated with a 48 V BMS and a commercial inverter was successfully operated under controlled laboratory conditions to supply a low-power external AC load.

The experimental results demonstrated that essential BMS functions—cell voltage monitoring, protection enforcement, and balancing—are sufficient to ensure safe and stable operation during both charging and discharging at power levels below 100 W. Measured voltage and current profiles confirmed correct activation of overvoltage and undervoltage protection thresholds, while observed reductions in cell voltage dispersion validated the effectiveness of the balancing mechanism.

Although the proposed setup does not implement grid synchronization, communication protocols, or active power management strategies required for full Vehicle-to-Grid (V2G) operation, it provides a practical and reproducible platform for preliminary testing and educational demonstrations of fundamental V2X concepts. The use of accessible, low-cost components highlights both the feasibility and the inherent limitations of non-automotive BMS solutions in bidirectional energy transfer applications.

Future work will focus on extending the experimental platform toward higher power levels, integrating measurement of individual cell currents, and exploring advanced control strategies to bridge the gap between simplified laboratory demonstrations and fully compliant V2X systems.

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