

Design and Implementation of a Wi-Fi-Enabled BMS for Real-Time LiFePO₄ Cell Monitoring [†]

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Abstract

This paper presents the design and implementation of a custom-built LiFePO₄ battery monitoring system that offers real-time visibility into the status of individual battery cells. The system is based on a Battery Management System (BMS) architecture while it is implemented the measuring of voltage, current, and temperature for each cell in a multi-cell pack. These key parameters are essential for ensuring safe operation, prolonging battery life, and optimizing energy usage in off-grid or mobile power systems. The system architecture is based on an ESP32 microcontroller that interfaces with INA219 and DS18B20 sensors to continuously measure individual cell voltage, current, and temperature. Data is transmitted wirelessly via Wi-Fi to a remote time-series database for centralized storage, analysis, and visualization. Experimental validation, conducted over a 15-day period, demonstrated stable system performance and reliable data transmission. Analytically, the findings indicate that utilizing an advanced smart charger for precise cell balancing and improving the physical layout for cooling led to superior thermal performance. Even with load currents nearly tripling to 110 mA, the system maintained a stable cell operating temperature range of 29.8 °C to 30.3 °C. This result confirms significantly reduced cell stress compared to previous iterations, which is critical for enhancing battery health and lifespan. The application of this project is aimed to demonstrates how a combination of open hardware components and lightweight network protocols can be used to create a robust, cost-effective battery monitoring solution suitable for integration into smart energy systems or remote IoT infrastructures.

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1. Introduction

Even since the introduction of lithium battery technologies, there has been a breakthrough in mobile applications like smart devices, remote controls, computers and electric vehicles [1]. Lithium batteries inherit many benefits including: high energy density, increased safety, and robustness, characteristics that are essential for producing compact electronic devices like smartphones or adding additional range and sizing to an electric vehicle (EV) [2]. Their operation is based on the flow from lithium ions from the

anode to the cathode and vice versa during charging and discharging process respectively through the electrolyte with a separator to protect from internal short circuits [3].

There are various lithium battery chemistries available including [4]:

1. Lithium Cobalt oxide (LiCoO_2) or LCO,
2. Lithium Manganese Oxide (LiMn_2O_4) or LMO
3. Lithium Nickel Cobalt Aluminum Oxide (LiNiCoAlO_2)—NCA
4. Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO_2)—NMC
5. Lithium Iron Phosphate (LiFePO_4)—LFP

LCO have a high energy density, thus they are popular for laptops and digital cameras but with a relatively short lifespan and thermal stability [5]. LMO, used previously in power tools, inherits fast charging and increased thermal stability than LCO although their energy density is almost 35% lower. NCA was introduced since 1999 and its specification include high energy density long lifespan and specific power, however due to escalated manufacturing costs and special safety monitoring systems to avoid possible breakdown, it is considered a chemistry for special applications like medical devices, aerospace industry and high-performance electric vehicles with cells manufactured by Panasonic or Tesla [6].

The two main types currently utilized are NMC and LFP: NMC is extremely popular by EV manufacturers as their very high energy density (over 200 Wh/kg), hence their range is extended, while being able to withstand very fast charging, two main specifications that EVs require [7]. In addition, they are thermally stable thus considered adequately safe. LFPs has practically achieved to be the top choice for almost every application, including EVs, smart device, e-mobility scheme. Their benefits include:

- Long service life with over 3000 to 5000 life cycles available;
- Extreme safety with a high thermal runaway threshold and very durable;
- Tolerant to full charge conditions,

Their drawbacks include lower nominal voltage, hence decreased energy density than NMC plus higher self-discharge rate [8]. Specifically, their main issue is the inconsistent performance on extreme temperatures, where at conditions below 0° Celsius their capacity and efficiency drop, while at high temperatures above 50 °C they lifespan decreases, which may even lead to a possible breakdown.

There are 3 main factors to describe battery operation [9]:

- State of Charge (SoC), describing the cells charge in %;
- State of Health (SoH), the battery maximum charge compared to nominal as the battery life indicator and
- State of Power, as the maximum power the battery can provide
- Depth of Discharge (DoD), as the capacity utilized at a certain use e.g., from 100% to 40% discharging.

Lithium batteries should operate within limited SoC range to avoid excess stress on the cells and maintain high SoH [10]. Excessive charging leads to lithium dendrites forming in the anode while high depth of discharge (DoD) increases temperature leading to reduced SoH and premature aging as chemical reactions are accelerated. Therefore, a modern and sophisticated Battery Management System (BMS) is required to monitor and optimize battery operation for maximum safety, performance and lifespan [11,12].

The goal of this paper is the proposal of a robust, compact and simple BMS scheme based on a Arduino compatible device from our previous work [13]. For this experiment, four IFR32700 batteries are utilized for testing, while voltage, current and temperature are continuously monitored through identical validated sensors like in [13]. The difference in this work is the utilization of external and renowned OEM chargers to check the performance and temperature variation of the cells on the same operating condition. All

values are collected through a 5 s time frame and then transferred to an internet application server via Wi-Fi for graphical representation.

2. Materials and Methods

For the testing requirements of the experiment, an expansion board was constructed, which includes a microcontroller with an integrated wireless network interface (Wi-Fi), a current sensor, and a temperature sensor. For the battery cells testing, four IFR32700 LFP battery cells by Deligreen were selected with a nominal voltage of 3.2 Volts, 6 Ampere-Hours capacity at a total of 19.2 Wh [14].

The microcontroller (MCU or Multipoint Control Unit) utilized is the ESP32 shown at Figure 1a, which offers high processing power with low power consumption. INA219 was selected as the sensor responsible to measure current and voltage (Figure 2b), and for monitoring temperature the DS18B20 module was exploited as depicted at Figure 2c below [15–17].

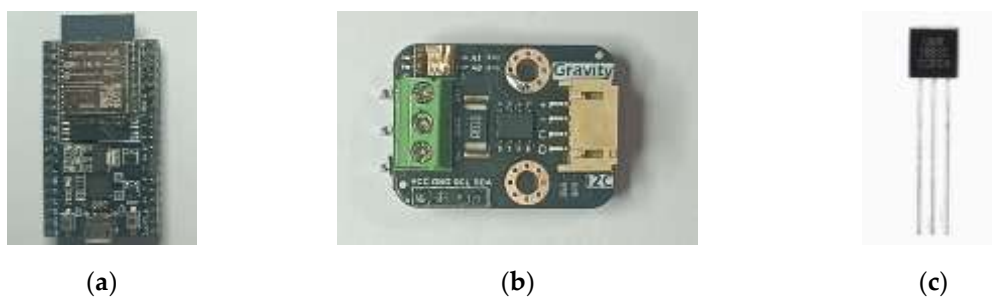


Figure 1. Parts utilized for the experiment: (a) Esp32 CPU; (b) INA219 voltage–current sensor; (c) Dallas ds18b20 temperature sensor.

Given that the BMS (40A-4S-E) used provides a pin series with the voltages of each battery cell, these signals were sent directly to the corresponding (analog) voltage reading ports on the microcontroller [18]. The ina219 uses the I2C protocol for data transfer (voltage and current), while the temperature sensor uses the 1-wire protocol as displayed in Figure 2.

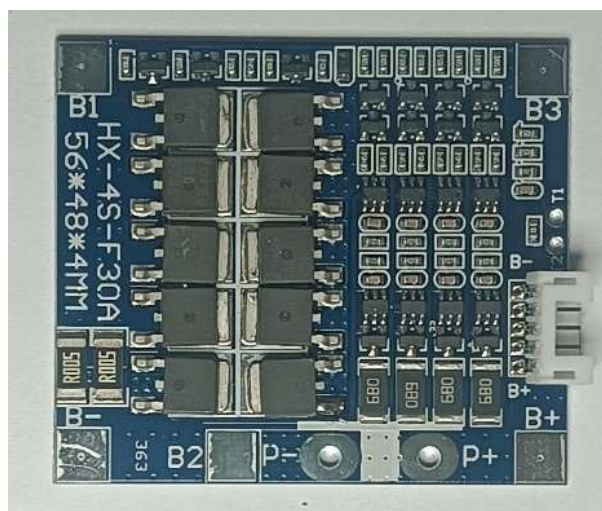


Figure 2. The BMS (4S) PCB for LFP batteries.

In terms of operation, current and temperature measurements are taken every 5 s, these values are filled in a table with the measured quantity, every minute the measurements are sent to the server, The values of each table's measurements are

compiled in JSON string format and sent to a database via a wireless network (Wi-Fi) using the POST method. The data was collected and visualized using an information system based on the Linux operating system. The database used is influxDB, which is ideal for time series measurements. [19] Grafana Lab software, portrayed in Figure 3, was employed for data visualization with the potential to provide additional processing to enhance results. The choice of both the operating system and the software were selected as open source, mainly as this option encourages the exchange of views and ideas, as well as participation in the open-source community [20].

The final experimentation layout is presented at Figure 3:

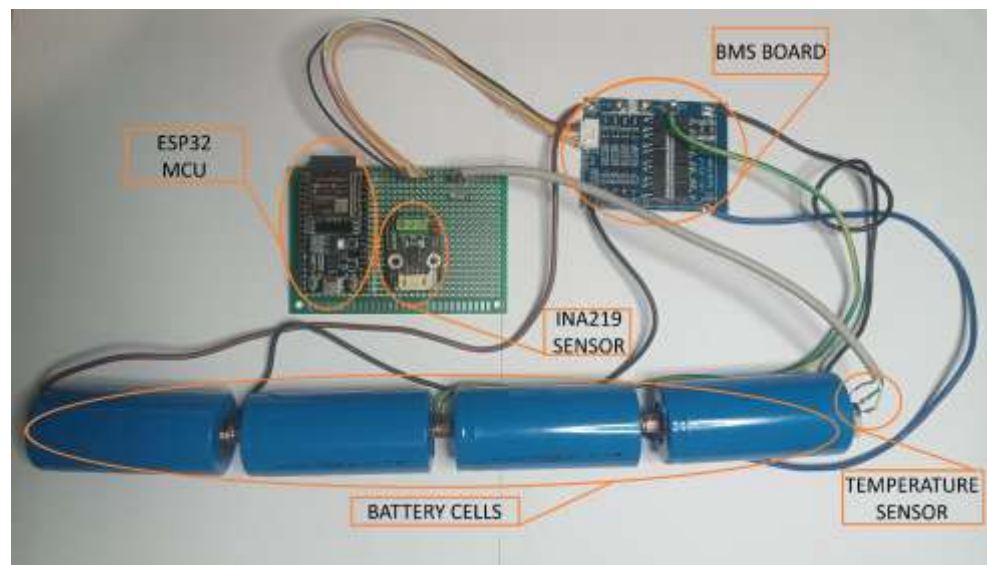


Figure 3. The experimental setup with an expansion board (MCU, BMS, Sensors).

Testing was conducted at typical summer temperatures (30–35 °C) just like the work conducted previously [13], at a household located in the province of Peristeri in Athens, Greece. As temperature plays a critical role in battery operation and to ensure consistency, conditions of the two experiments had to be identical for direct comparison. Total measurements gathered are 25,000, throughout a 15 days period. The main difference and the objective of this experiment is to validate if charging through an advanced smart charger like the Maxbuster Mc5000 by SkyRC for precise charging and cell balancing [22].

3. Results and Discussion

The first part of the experiment is to validate whether the temperature sensor position will show any abnormalities on temperature measurements. When placed on the negative side of the battery layout where maximum current is shown, temperature was at its highest value but not excessively, ranging between 0.2 to 0.8 °C compared to middle points or the positive terminal. So, this placement is considered ideal to ensure that battery will not reach values above the manufacturer safety zone. This is proven at [13] as well, and the results of temperature differentiation are presented at Figure 4 below:

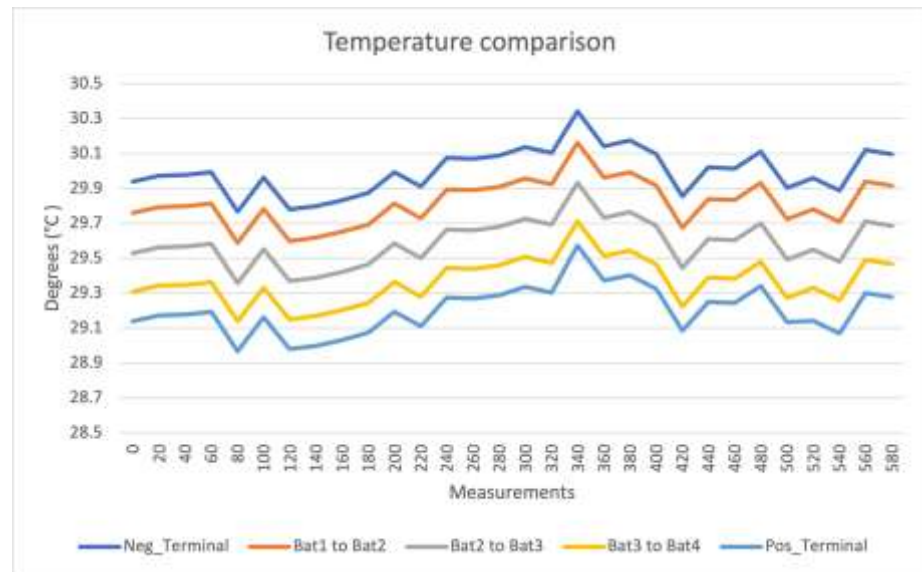


Figure 4. Temperature comparison specified to DS18B20 sensor installation.

As series connection was selected the total voltage is the sum of all 4 batteries hence it can reach up to 14.5 V. However, voltage of each cell is required for direct comparison with precious work [13] so by utilizing INA219 plus an external charger-balancer, the distinct values of each cell are available. As a typical 0.5% error can be reported in both the INA219 and DS18B20, external monitoring tools were utilized to validate the results. Temperature and load stress are minimal to ensure that the reading error is zero.

As depicted in Figure 5, battery temperature is lower compared to [13] even though load is increased. This is mainly affected by the battery oversizing in addition to proper balancing through charging. Batteries stress is decreased; temperature is minimized so aging is enhanced.

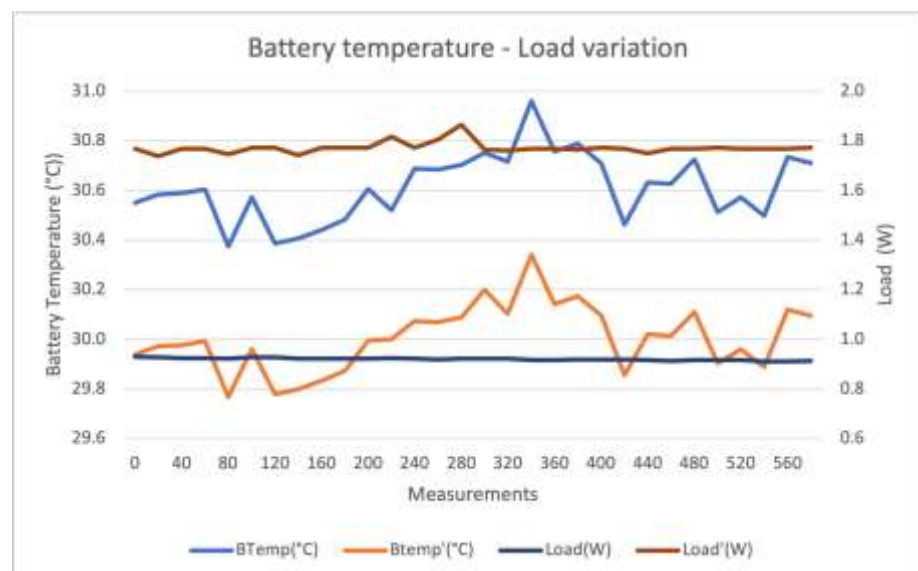


Figure 5. Temperature comparison correlation to load variation.

Moreover, the effect of battery output is compared to the cell internal temperature thus the increase of battery stress that can lead to aging. Ambient temperature on this experiment was similar to the last one so it slightly affects the results. As shown in Figure 6, the total power required by the load is higher, almost double, however as the battery cells are oversized and properly balanced, while the distance between them and the board

is increased for cooling, internal temperature is even less around 30 °C which is ideal. The state of charge for this test ranged between 40–80% mostly, for optimal performance. Below the 40% threshold, the BMS reached its minimum supply voltage, so it turned off. Charging to 100% was utilized 5 times only for cell balancing which is useful for LFP batteries at certain points for optimization [23]. Even at this occasion, battery temperature was kept stable for safety concerns at low amperage with the external charger all at a robust and affordable layout.

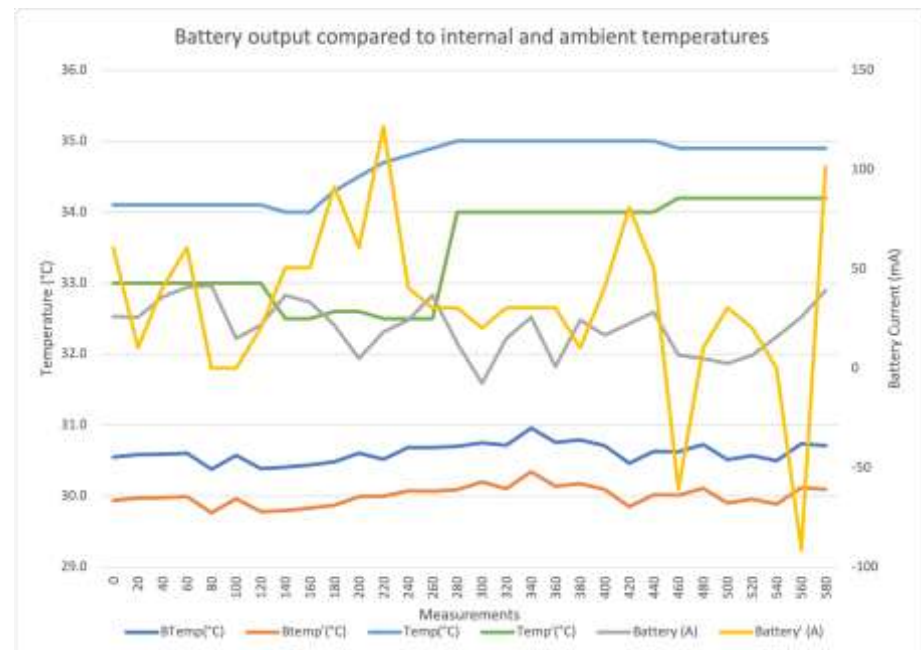


Figure 6. Connection of battery output in mA to cell internal and ambient temperatures.

Regarding communication reliability a typical 2% error is allowed, as the Arduino has a certain time frame of 5 s from design, however as the load and thermal stress of the cells are limited, there is no effect on the integrity of the system. Typical mean error for the statistical analysis accounts for a total of 0.5% as the monitoring pattern is selected thoroughly to ensure liability and limited variance. Finally, the results of this experiment compared to the previous one in [13] are provided below at Table 1:

Table 1. Comparison of previous work and this project.

Parameter	Previous Work [13]	This Work
SoC Range	60–100%	40–100%
SoH at end	100%	100%
SoP	14.8 A	20 A ¹
DoD	40%	40–60%
Maximum Current (mA)	40 mA	110 mA
Temperature Range	30.3 to 31 °C	29.8 to 30.3 °C
Faster Cooling	X	✓

¹ Not directly compatible due to different battery layout.

4. Conclusions

This study successfully demonstrated the design, implementation, and validation of a low-cost, Wi-Fi-enabled Battery Management System for real-time, per-cell monitoring of LiFePO₄ battery packs. The primary objective—to create an accessible and scalable

monitoring tool—was achieved using an ESP32 microcontroller paired with commodity sensors, which reliably transmitted granular data to a remote server for analysis.

The experimental results confirmed the system's efficacy and provided critical insights into battery health management. A key finding was the significant improvement in thermal stability achieved through the integration of an external smart charger for precise cell balancing. Compared to previous work, the system maintained a lower and more stable operating temperature range (29.8 °C to 30.3 °C), even when subjected to nearly triple the load current (110 mA). This outcome empirically validates that meticulous cell balancing and an optimized physical layout for cooling are paramount in mitigating thermal stress, thereby enhancing the State of Health (SoH) and extending the operational lifespan of the battery pack. Furthermore, the placement of the temperature sensor at the negative terminal was confirmed as the optimal location for capturing peak thermal readings all in a robust and affordable design. Even though the BMS scheme possible failures and balances the battery cells output, the charging power cannot be controlled as a sophisticated charger would be required but this layout will be tested as future work.

In conclusion, this work presents a robust and cost-effective open-hardware solution that rivals the functionality of more expensive commercial BMS units. The system modularity and reliance on open-source platforms make it highly adaptable for various applications, from academic research and DIY energy storage projects to integration within larger Internet of Things (IoT) and smart energy infrastructures. Future work could expand upon this platform by incorporating more advanced SoH and State of Charge (SoC) estimation algorithms and developing a more sophisticated user interface for predictive analytics. In addition, comparison with existing low-cost BMS/monitoring platform e.g., openBMS, TI BQ series, or recent IoT BMS schemes will be concluded.

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References

1. Deng, H.; Aifantis, K.E. Applications of Lithium Batteries. In *Rechargeable Ion Batteries*; Kumar, R., Aifantis, K., Hu, P., Eds.; Wiley: Hoboken, NJ, USA, 2023; pp. 83–103, ISBN 9783527350186.
2. Guarnieri, M. Secondary Batteries for Mobile Applications: From Lead to Lithium [Historical]. *IEEE Ind. Electron. Mag.* **2022**, *16*, 60–68. <https://doi.org/10.1109/MIE.2022.3212242>.
3. Comanescu, C. Ensuring Safety and Reliability: An Overview of Lithium-Ion Battery Service Assessment. *Batteries* **2025**, *11*, 6. <https://doi.org/10.3390/batteries11010006>.
4. Gao, Z.-W.; Lan, T.; Yin, H.; Liu, Y. Development and Commercial Application of Lithium-Ion Batteries in Electric Vehicles: A Review. *Processes* **2025**, *13*, 756. <https://doi.org/10.3390/pr13030756>.

5. Nyamathulla, S.; Dhanamjayulu, C. A Review of Battery Energy Storage Systems and Advanced Battery Management System for Different Applications: Challenges and Recommendations. *J. Energy Storage* **2024**, *86*, 111179. <https://doi.org/10.1016/j.est.2024.111179>.
6. Nájera, J.; Arribas, J.R.; De Castro, R.M.; Núñez, C.S. Semi-Empirical Ageing Model for LFP and NMC Li-Ion Battery Chemistries. *J. Energy Storage* **2023**, *72*, 108016. <https://doi.org/10.1016/j.est.2023.108016>.
7. Elmahallawy, M.; Elfouly, T.; Alouani, A.; Massoud, A.M. A Comprehensive Review of Lithium-Ion Batteries Modeling, and State of Health and Remaining Useful Lifetime Prediction. *IEEE Access* **2022**, *10*, 119040–119070. <https://doi.org/10.1109/ACCESS.2022.3221137>.
8. Ngoy, K.R.; Lukong, V.T.; Yoro, K.O.; Makambo, J.B.; Chukwuati, N.C.; Ibegbulam, C.; Eterigho-Ikelegbe, O.; Ukoba, K.; Jen, T.-C. Lithium-Ion Batteries and the Future of Sustainable Energy: A Comprehensive Review. *Renew. Sustain. Energy Rev.* **2025**, *223*, 115971. <https://doi.org/10.1016/j.rser.2025.115971>.
9. Menye, J.S.; Camara, M.-B.; Dakyo, B. Lithium Battery Degradation and Failure Mechanisms: A State-of-the-Art Review. *Energies* **2025**, *18*, 342. <https://doi.org/10.3390/en18020342>.
10. Chen, G.; Xia, X.; Zhao, X.; Zeng, X.; Ouyang, T.; Feng, H. A Balanced SOH-SOC Control Strategy for Multiple Battery Energy Storage Units Based on Battery Lifetime Change Laws. *Electr. Eng.* **2025**, *107*, 7725–7736. <https://doi.org/10.1007/s00202-024-02944-1>.
11. Rimpas, D.; Kaminaris, S.D.; Aldarraji, I.; Piromalis, D.; Vokas, G.; Papageorgas, P.G.; Tsaramirsis, G. Energy Management and Storage Systems on Electric Vehicles: A Comprehensive Review. *Mater. Today Proc.* **2022**, *61*, 813–819. <https://doi.org/10.1016/j.matpr.2021.08.352>.
12. Krishna, G.; Singh, R.; Gehlot, A.; Akram, S.V.; Priyadarshi, N.; Twala, B. Digital Technology Implementation in Battery-Management Systems for Sustainable Energy Storage: Review, Challenges, and Recommendations. *Electronics* **2022**, *11*, 2695. <https://doi.org/10.3390/electronics11172695>.
13. Rimpas, D.; Orfanos, V.A.; Chalkiadakis, P.; Christakis, I. Design and Development of a Low-Cost and Compact Real-Time Monitoring Tool for Battery Life Calculation. *Eng. Proc.* **2023**, *58*, 17.
14. Deligreen IFR-32700 LFP Battery Datasheet. Available online: [https://evparts.ir/uploadfile/file_portal/site_4540_web/file_portal_end/IFR32700N60-SPEC_FB0819-R01-IFR32700N60\(1\).pdf](https://evparts.ir/uploadfile/file_portal/site_4540_web/file_portal_end/IFR32700N60-SPEC_FB0819-R01-IFR32700N60(1).pdf) (accessed on 5 August 2025).
15. ESP32-WROOM-32 Datasheet. Available online: https://www.espressif.com/sites/default/files/documentation/esp32-wroom-32_datasheet_en.pdf (accessed on 5 August 2025).
16. INA219 I2C—Digital Wattmeter SKU: SEN0291 Datasheet. Available online: <https://wiki.dfrobot.com/Gravity:%20I2C%20Digital%20Wattmeter%20SKU:%20SEN0291> (accessed on 5 August 2025).
17. DS18B20 Programmable Resolution 1-Wire Digital Thermometer Datasheet. Available online: <https://cdn.sparkfun.com/datasheets/Sensors/Temp/DS18B20.pdf> (accessed on 6 August 2025).
18. BMS-40A-4S-E Datasheet. Available online: https://www.mantech.co.za/datasheets/products/BMS-40A-4S_SGT.pdf (accessed on 5 August 2025).
19. Kychkin, A.; Deryabin, A.; Vikentyeva, O.; Shestakova, L. Architecture of Compressor Equipment Monitoring and Control Cyber-Physical System Based on Influxdata Platform. In Proceedings of the 2019 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), Sochi, Russia, 25–29 March 2019; IEEE: Sochi, Russia, 2019; pp. 1–5.
20. Grafana Labs—The Open Platform for Analytics and Monitoring. Available online: <https://grafana.com/> (accessed on 7 August 2025).
21. SKYRC MC500 Datasheet. Available online: <https://manuals.plus/skyrc/mc5000-cylindrical-battery-charger-and-analyzer-manual> (accessed on 8 August 2025).
22. Zhou, R.; Lu, J.; Wu, Y.; Zhang, H.; Yan, K. Research on Lithium Iron Phosphate Battery Balancing Strategy for High-Power Energy Storage System. *Energies* **2025**, *18*, 3671. <https://doi.org/10.3390/en18143671>.

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