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Preliminary Hazard Analysis and Functional Safety Concept for a 2nd Life Battery Energy Storage System

Rigas Frangoudis[1], Dimitra Spanoudaki[1]*, Elisavet Elvanoglou[1] and Sotiris Athanasiou[2]

Abstract

By 2030, the growing volume of retired EV batteries presents an opportunity for reuse in stationary energy storage systems (ESS). This paper outlines a **Preliminary Hazard Analysis (PHA)** and a **Functional Safety Concept (FSC)** for 2nd life **Battery Energy Storage Systems (BESS)**. It highlights key risks, including system analysis using **Electrochemical Impedance Spectroscopy (EIS)** and a wireless **Battery Management System (BMS)**. The analysis ensures compliance with safety standards and lays the groundwork for future pilot implementations.

Introduction

Reuse of EV Batteries for Stationary Applications As the volume of retired EV batteries grows, with over 5 million tons expected by 2030, repurposing the 2nd life batteries for stationary energy storage systems (ESS) is a sustainable solution. These batteries retain 70-80% of their original capacity and can support grid balancing. This paper outlines a **Preliminary Hazard Analysis (PHA)** and a **Functional Safety Concept (FSC)** for 2nd life BESS. It emphasizes the critical role of managing hazards unique to these systems, particularly through a robust **Battery Management System (BMS)** that addresses both natural and technical risks.

Methodology

Hazard Identification and Safety in 2nd Life Battery Systems

- **Location**: PPC Innovation Hub, Kantza, Attica (37° 59'37"N, 23° 51'08"E).
- **Earthquake Risk**: Moderate hazard (PGA = 0.229g) impacting stability design.
- **Temperature**: Greece experiences extreme heatwaves (43-44° C), requiring robust cooling systems for lithium-ion batteries.

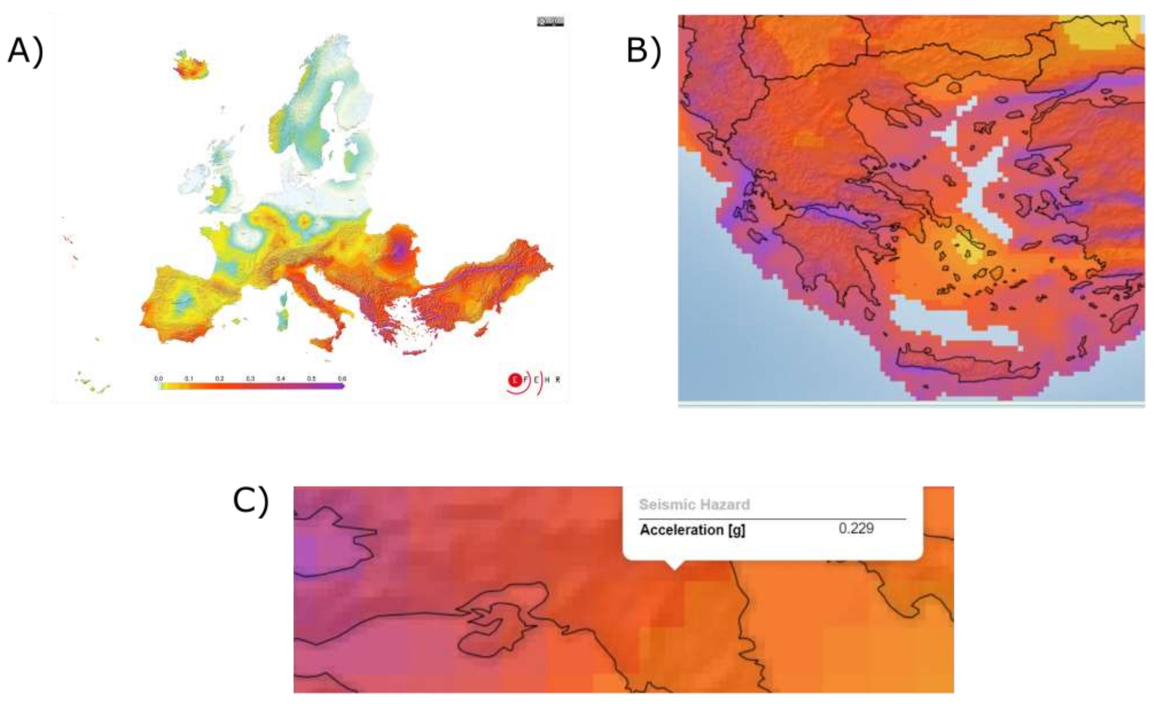
Lithium-Ion and Chemical Hazards

- **Cooling**: Prevent thermal runaway by maintaining temperatures below 60° C and above 0° C.
- **Fire Risk**: Lithium-ion cells release toxic gases during thermal events. Safety protocols are essential.
- **Electrolyte Leakage**: Flammable and corrosive.
- **Thermal Runaway**: Can cause fires/explosions.
- **Decomposition**: Emissions of toxic gases (HF, CO).

Battery Management System (BMS) Hazards

- **BMS Role**: Monitors voltage, temperature, and current.
- **Risks**: Overvoltage, undervoltage, overheating, and overcurrent can lead to fires or reduced battery life.
- **Redundancy**: Crucial for safety, requiring continuous monitoring of system parameters.

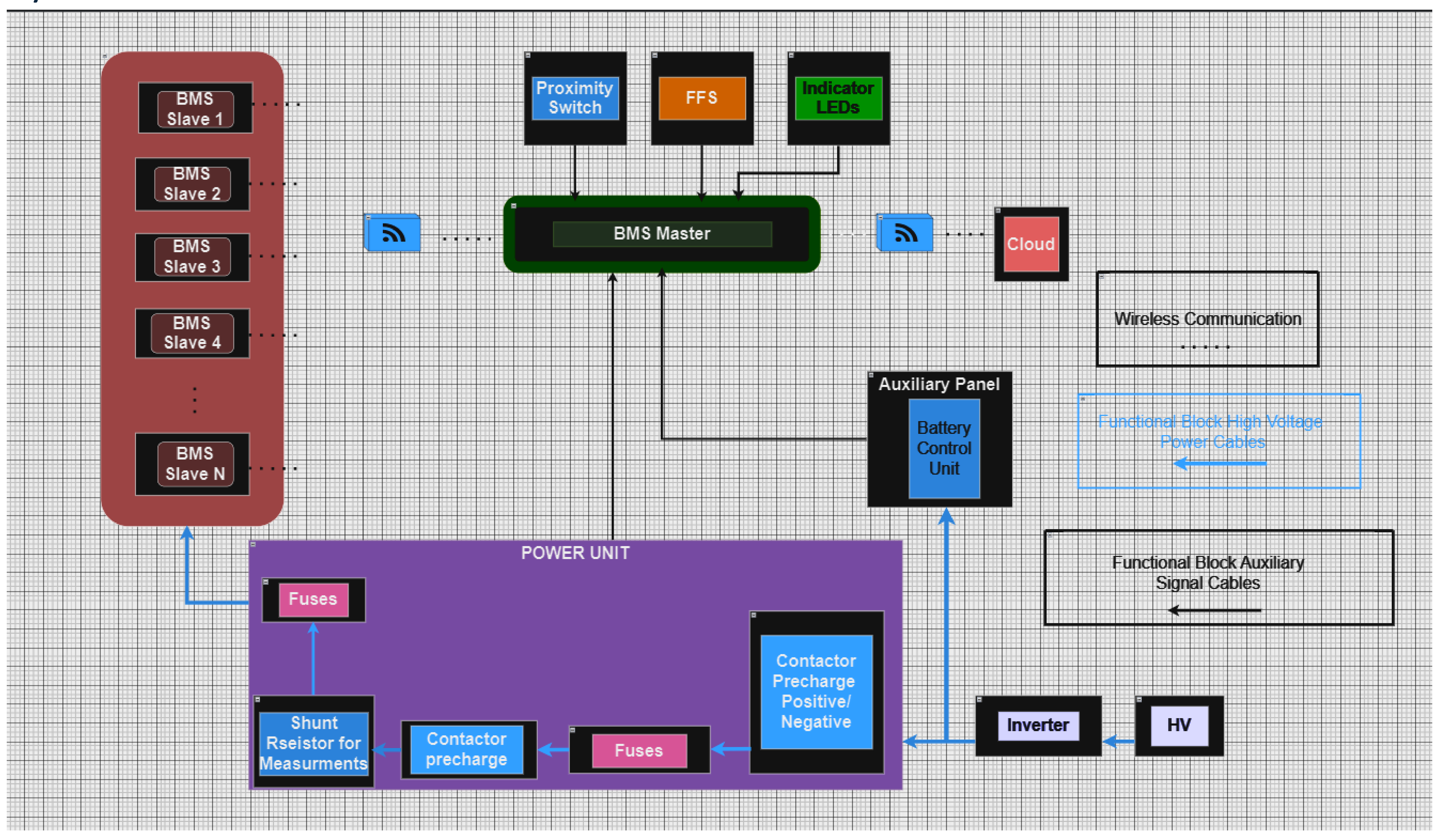
Safety in 2nd life battery systems is critical due to natural and chemical hazards. Effective cooling, robust BMS, and emergency protocols are necessary for safe operation.



Technical Safeguards and Functional Safety Concept

Technical Safeguards and FSC of the 2nd life BESS is centered around the BMS, which acts as the primary technical safeguard. The FSC ensures the reliable operation of the system by mitigating the specific hazards associated with 2nd life batteries.

- **Thermal Management**: Thermal management is a critical function of the BMS, especially in high-temperature conditions like those found in Greece. The system must be equipped with redundant temperature sensors and an active cooling mechanism to prevent overheating. Failure to maintain appropriate thermal conditions can lead to thermal runaway, one of the most significant risks in battery systems.
- **Electrical Safeguards**: The system must be protected against electrical failures such as short circuits and overcurrent. Electrical safeguards, including fuses and circuit breakers, ensure that any fault in the system is quickly isolated to prevent larger system failures. Structural and Environmental Safeguards: In addition to internal electrical and thermal protections, the system must be designed to withstand environmental factors such as earthquakes and extreme temperatures.
- **Mechanical safeguards**: Structural reinforcements and housing will be designed to protect the system from seismic activity while preventing external heat from compromising the battery system's safety.
- **Wireless Communication Safeguards**: Given the reliance on wireless communication for the Electrochemical Impedance Spectroscopy (EIS) used in estimating the battery's State-of-Charge and State-of-Temperature, robust communication protocols must be in place. Redundant communication channels ensure that even if one path fails, control over the system is maintained.



FSC	Description
BMS Slave Board (BMS Slave 1, BMS Slave 2, etc)	BMS slaves are responsible for monitoring individual cells or groups of cells in a battery pack. They collect data such as voltage, temperature, and current and they send this information to the Master BMS.
BMS Master Board	The BMS Master Board receives data from the BMS slaves and manages the overall battery system. It ensures that the battery operates within safe limits, balancing cells and protecting them from over-charging and over-discharging.
Proximity Switch	It is used to detect the physical presence or position of components in the system, such as the connection of battery modules or other key components.
FFS (Fire Fighting System)	The FFS is a fire prevention system, designed to mitigate fires associated with failure of the BESS, like in a thermal runaway.
Indicator LEDs	These LEDs provide visual feedback or status indications for different parts of the system, such as system health, charging status, or fault conditions.
Shunt Resistor for measurements	A shunt resistor measures the current flowing through the system. By measuring the voltage drop across the shunt, the system can calculate the current, helping in monitoring power flow and ensuring safe operation.
Contactor Pre-charge	Pre-charge contactors limit the initial inrush of current when the battery system is first connected to the rest of the circuit. This protects damaged by a sudden surge of power.

environmental safeguards, ensures that the system can operate reliably and safely in the face of natural and technical hazards. Further validation is required through pilot projects to refine these safety protocols and ensure the system's long-term viability.

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Contact Information

Corresponding author's Name: Dimitra Spanoudaki

[1]Sunlight Group Energy Storage Systems, 67200, Xanthi, Greece
[2]Sunlight Group Energy Storage Systems,14564, Attica, Greece
d.spanoudaki@sunlight.gr

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