

A Systems Engineering Approach to the Application and Processes of Hybrid Energy Storage Modules

Research Experience for Undergraduates

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- Default placeholder for your prototyping and test results. Prototyping can be interpreted in a broad sense—not only hardware, but high-fidelity simulations.

Executive Summary

Modeling project serves as a foundational test bed for the integration of Model-Based Systems Engineering (MBSE) practices into a preexisting Hybrid Energy Storage Module (HESM), enabling validation of synchronization logic and power quality controls. Utilizing the SysML language and Cameo Systems Modeler, a modular framework was developed that aims to meets current MIL STD-1399 requirements and is explicitly designed to integrate into the HESM. The SysML diagrams, such as block definition, activity, and internal block diagrams, act as a living blueprint, ensuring scalability for future energy storage modeling, hardware-in-the-loop testing, and operator training simulations.

Background

- The United States Navy has seen a transition into more electric-dependent energy systems such as Hybrid Energy Storage Modules (HESM). These devices synergize energy-dense lithium-ion batteries with power-dense capacitors. Capacitors buffer extreme loads while batteries provide sustained storage, extending generator lifespans. This test bed, created using Model-Based Systems Engineering (MBSE) with Cameo/SysML, creates a scalable foundation for integration with an existing HESM by developing interfaces and simulation ready diagrams that model transient load responses, allowing for future expansion. By capturing all component libraries and constraints in SysML, a framework is created that enables virtual testing of HESM-genset coordination and crew training, allowing for more dynamic simulations of power systems.

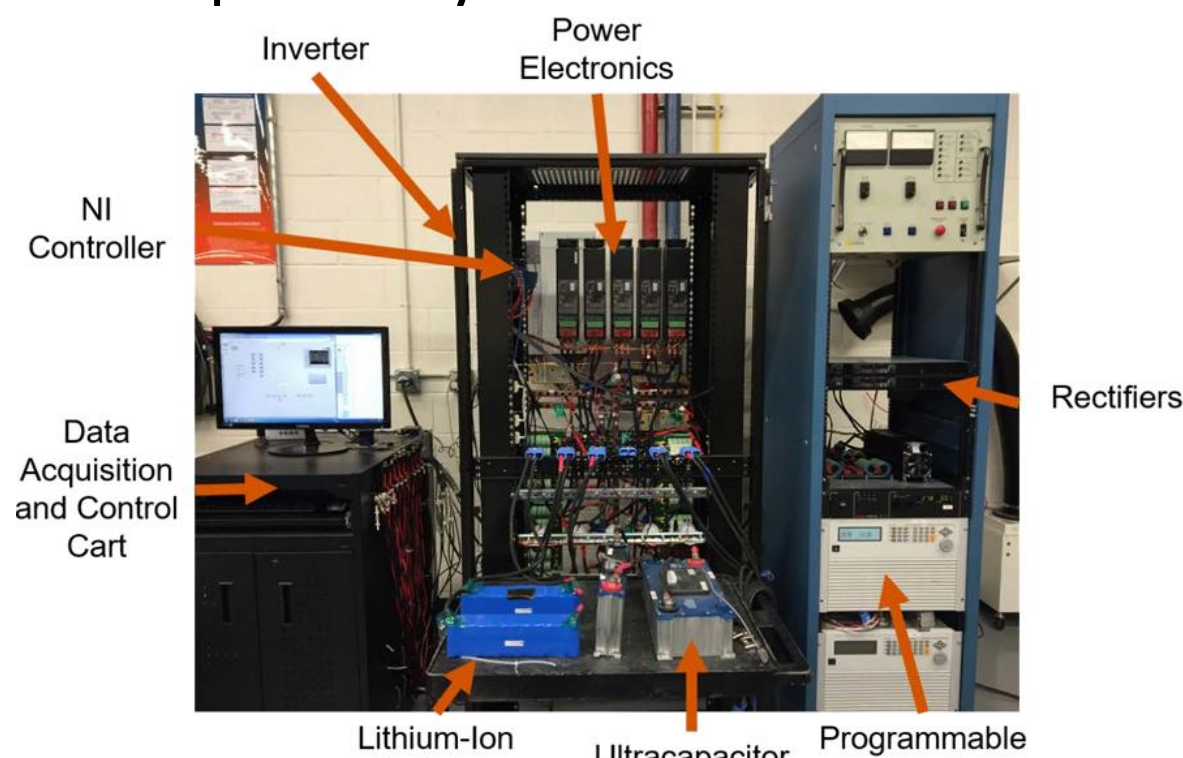


Figure 1. Photo of the HESM

Experimental Setup

- Use SysML as a mechanism for presenting and explaining components of the power generation portion of the entire HESM
- Outline the functionality of the HESM using model-based systems engineering in Cameo

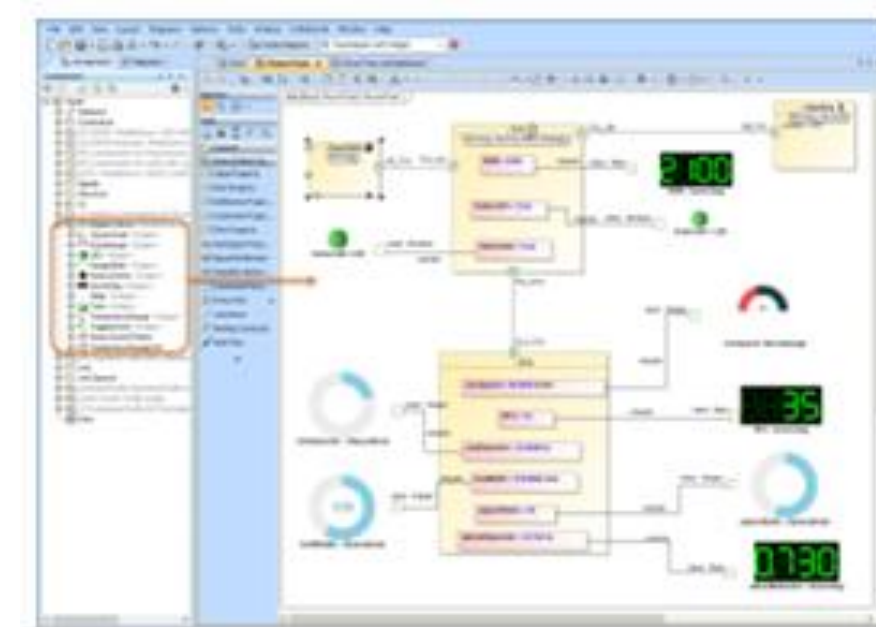


Figure 2. Example of Cameo interface

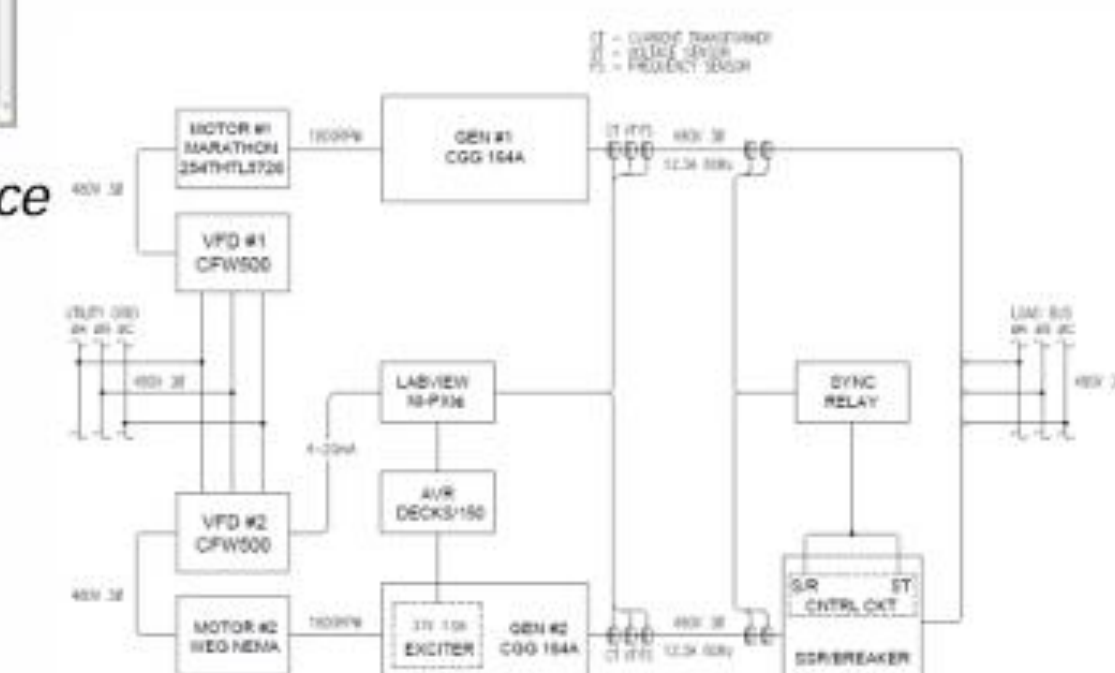


Figure 3. System Block Diagram from grid to HESM load bus

Experimental Test Plan

The Hybrid Energy Storage Module (HESM) was modeled using the MagicGrid Convention of Model-Based Systems Engineering. For the scope of this project, section 3 of the White Box of the problem domain will be shown. The problem domain is the stage of a project where stakeholder requirements are defined to identify what a system needs to operate. The White Box is a section within the problem domain that details the inputs and outputs that major subsystems within a system of interest will need to have with each other. Section 3 of the White Box, or W3 for short, explains what hierarchy and interactions the parts and subsystems must have. The block definition diagram will explain the system hierarchy. The internal block diagram will explain the flow process between the parts and subsystems.

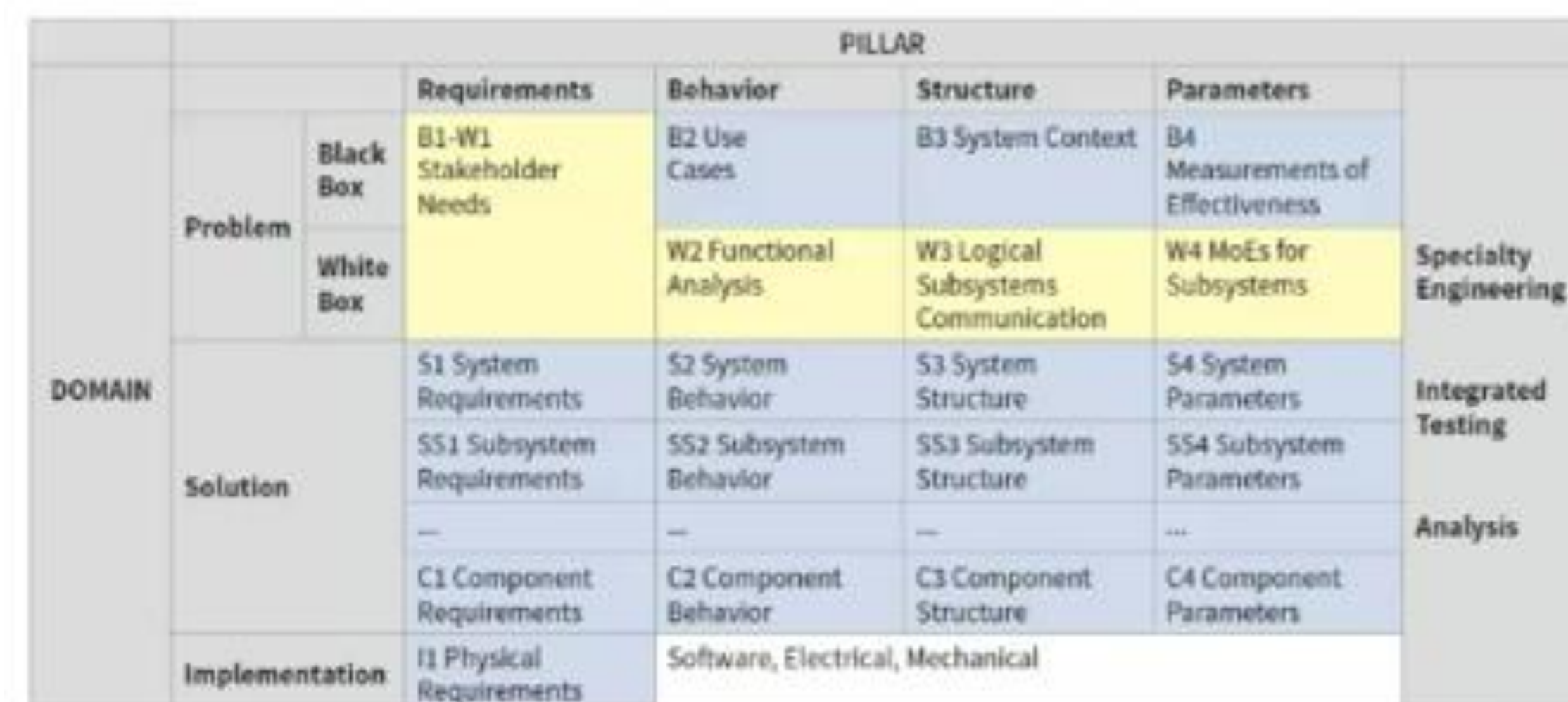


Figure 4. The MagicGrid Problem Domain

Experimental Results

- From Section W3 of the problem domain, the following diagrams were produced.

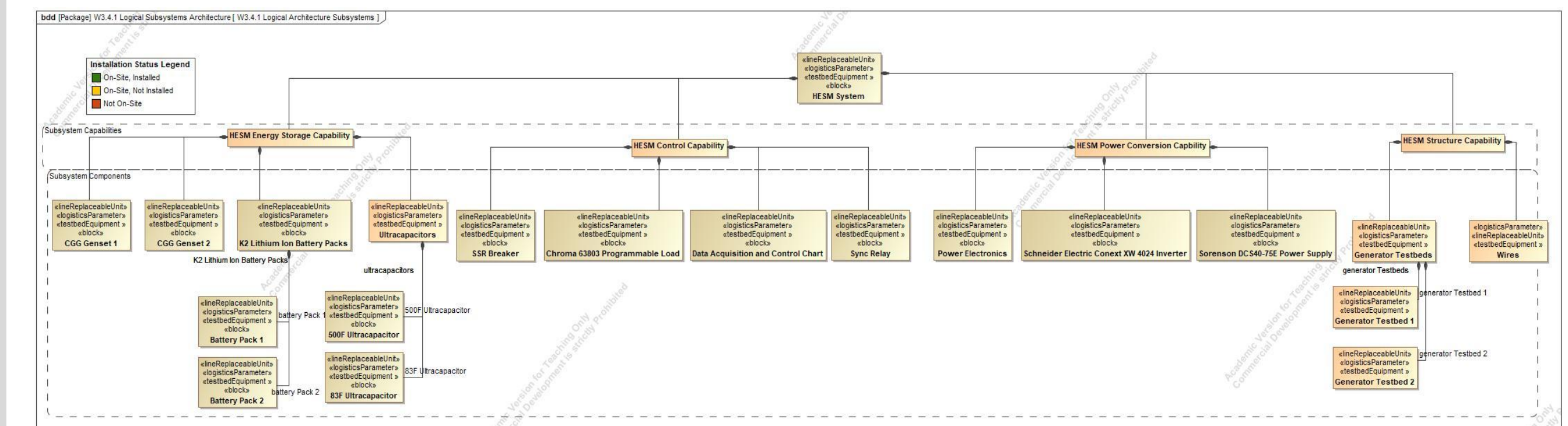


Figure 5. The Block Definition Diagram

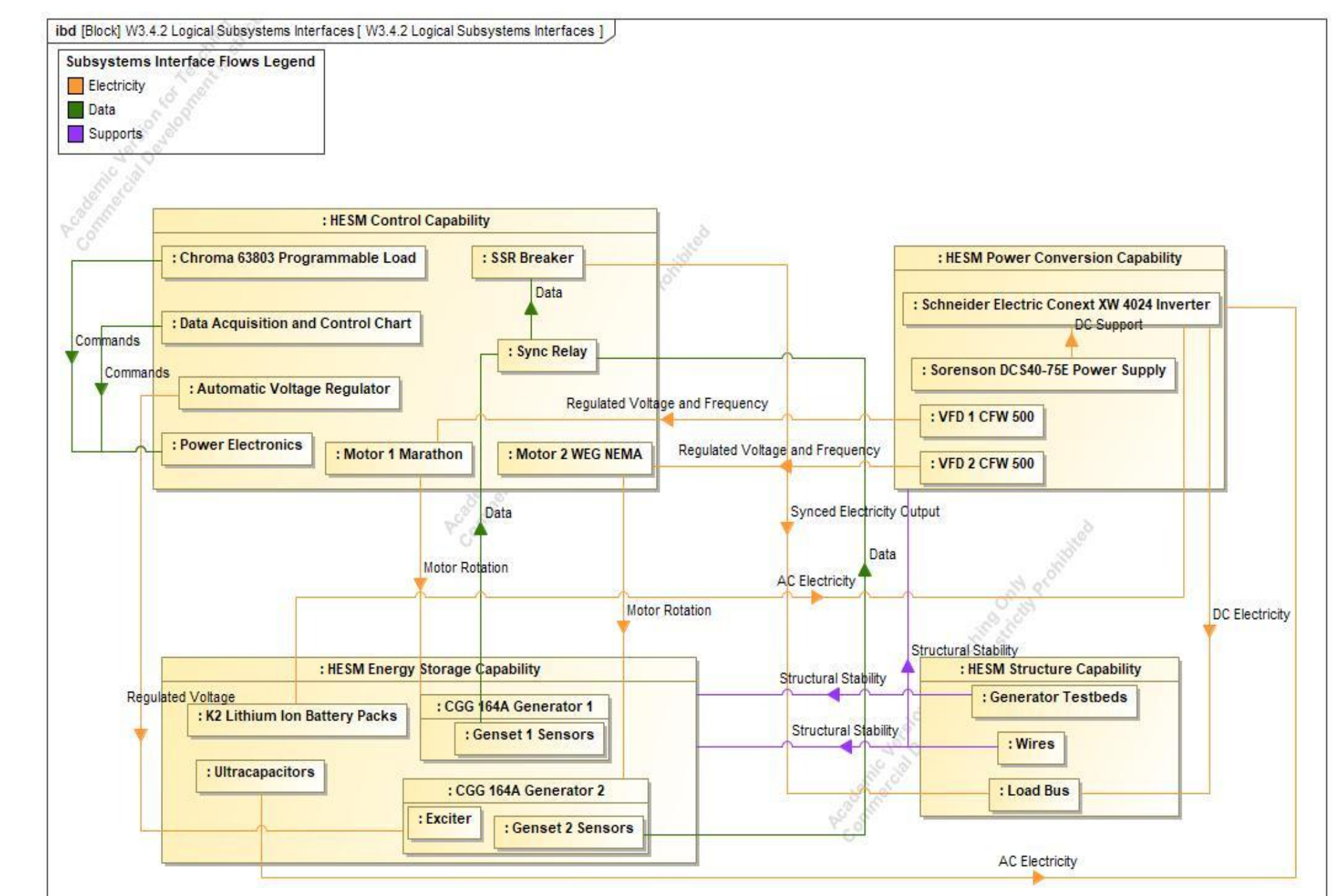


Figure 6. The Internal Block Diagram

Conclusions

- Current SysML implementation establishes a foundational model for microgrid architecture.
- Next-phase development will prioritize Navy-requested deliverables:
 - Risk analysis diagrams
 - Detailed requirement diagrams (traceability to MIL-STD-1399)
- The SysML framework demonstrates scalability for the HESM but requires additional development increase user context and meet operational requirements

References

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2. Johnston, Cameron, et al. Microgrid Report. University of Texas at Arlington, Aug. 2024.
3. Cohen, Isaac J. "The Design and Control of a Battery-Supercapacitor Hybrid Energy Storage Module for Naval Applications." University of Texas at Arlington, 2016.
4. Morkevicius, Aiste A. A. "MagicGrid® Book of Knowledge A Practical Guide to Systems Modeling using MagicGrid from No Magic." No Magic, Inc. 2018.