Overcoming Key Challenges in Developing Robust System Architecture: A Case Study on Automotive Battery Systems

In this blog, we delve into the topic of system architecture, using lithium-ion battery systems as an illustrative example. The system architecture significantly influences the robust design of the battery system and is crucial because it directly contributes to defining and fulfilling the required product functionalities and characteristics.

Beyond the necessary electromechanical, Software, electrochemical and material technology competencies for battery system design, a comprehensive understanding of Systems Engineering (SE) is essential. Numerous diverse aspects of battery system design and development fall within the ambit of the SE discipline. The primary reason for considering SE throughout the product development lifecycle is the highly complex nature of the battery system, which incorporates multiple functionalities. A lack of basic SE knowledge can result in a highly challenging environment due to system complexity and interdisciplinary work. Over the years, I have increasingly noticed a growing understanding among automotive company management of the need for an SE-centric approach. This is primarily due to the recognition of the high complexity of the target product.

The state-of-the-art development process for a battery system or its components, such as the Battery Management System (BMS) in the automotive industry, utilizes the so-called V-model. Additional ISO standards, such as ISO 26262 and Automotive SPICE process assessment and process reference model, which rely on the V-model, are also applied.

Figure 1 schematically depicts the product development process. Here, the focus is mainly on SE and software engineering of BMS development according to the V-Model. This approach is customer-centric, with battery system product development based on customer requirements. The phases highlighted in blue are those where the SE discipline plays a pivotal role, assuming the major activities and responsibilities. Based on the derived system architecture elements and their functionalities, the sub-disciplines - Hardware (HW), Software (SW), and Mechanical Engineering (ME) - begin to design and implement their respective component requirements and functionalities. In simple terms, the left side of the V-Model covers the battery system design, while the right side manages its integration and testing. For simplicity's sake, the functional safety aspect is not considered in this discussion.

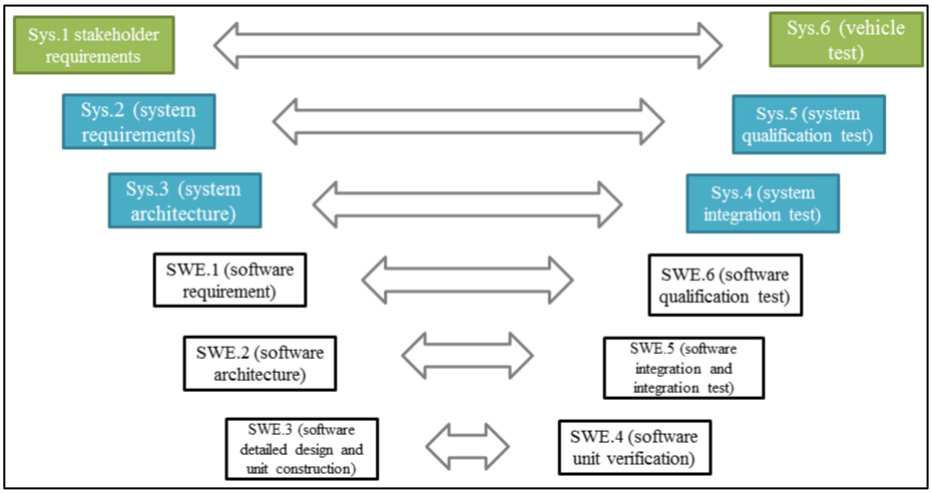


Figure 1: Product development process according to V-Model [1]

In general, the way forward is straightforward: the required product functionalities should be broken down into sub-functionalities. To simplify, sub-functionalities are defined based on the overall system functionality. However, the functional structure should remain solution-independent, often serving as a foundation for later solution principles. Similar to functional structure, the product physical architecture necessitates defining and investigating the physical interdependencies between the sub-components. In alignment with the transformation of sub-functionalities into sub-solutions, the product structure of a battery system can be delineated. Figure 2 illustrates a battery system product architecture. Please note that this figure provides a very simplified version, and the interdependencies between components are not depicted.

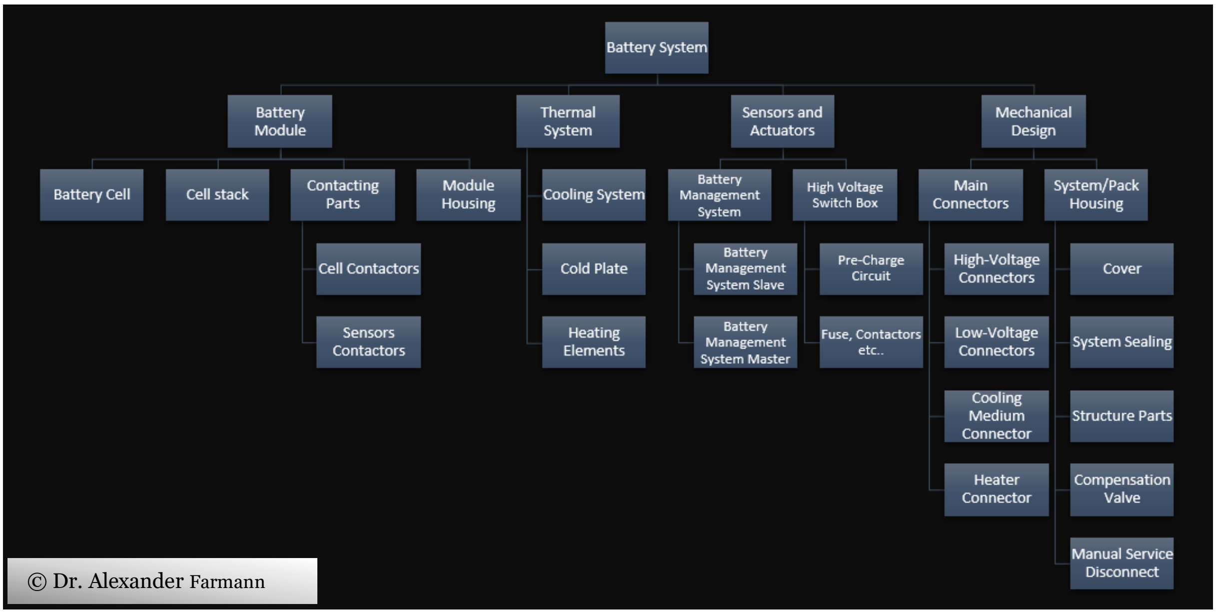
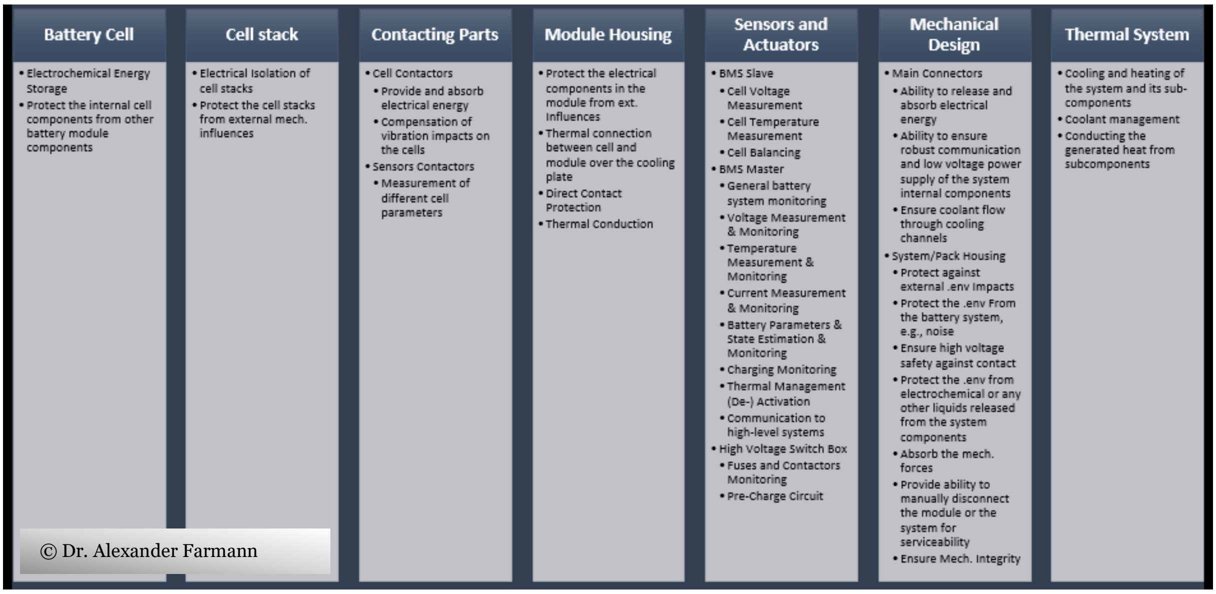


Figure 2: A simplified generic battery system product architecture.

Based on the derived product physical architecture depicted in Figure 2, the functional structure can be defined. For each of the main system components, the high-level functions that the respective component should fulfill are outlined (see Figure 3). Please note that this list of functionalities is not comprehensive and should be viewed by the reader as a basic reference.



Battery Cell	Cell stack	Contacting Parts	Module Housing	Sensors and Actuators	Mechanical Design	Thermal System
• Electrochemical Energy Storage • Protect the internal cell components from other battery module components	• Electrical Isolation of cell stacks • Protect the cell stacks from external mech. influences	• Cell Contactors • Provide and absorb electrical energy • Compensation of vibration impacts on the cells • Sensors Contactors • Measurement of different cell parameters	• Protect the electrical components in the module from ext. Influences • Thermal connection between cell and module over the cooling plate • Direct Contact Protection • Thermal Conduction	• BMS Slave • Cell Voltage Measurement • Cell Temperature Measurement • Cell Balancing • BMS Master • General battery system monitoring • Voltage Measurement & Monitoring • Temperature Measurement & Monitoring • Current Measurement & Monitoring • Battery Parameters & State Estimation & Monitoring • Charging Monitoring • Thermal Management (De-) Activation • Communication to high-level systems • High Voltage Switch Box • Fuses and Contactors Monitoring • Pre-Charge Circuit	• Main Connectors • Ability to release and absorb electrical energy • Ability to ensure robust communication and low voltage power supply of the system internal components • Ensure coolant flow through cooling channels • System/Pack Housing • Protect against external .env Impacts • Protect the .env From the battery system, e.g., noise • Ensure high voltage safety against contact • Protect the .env from electrochemical or any other liquids released from the system components • Absorb the mech. forces • Provide ability to manually disconnect the module or the system for serviceability • Ensure Mech. Integrity	• Cooling and heating of the system and its sub-components • Coolant management • Conducting the generated heat from subcomponents

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Figure 3: A simplified overview of a function structure of a battery system architecture.

After defining the main functions depicted in Figure 4, each of the respective main functions is subdivided into various functional design-relevant architecture requirements. The main functions, especially in the case of Hardware (HW) and Software (SW) functionalities, must be divided into three main subcategories: 1- Measurement; 2- Processing; and 3- Monitoring. It should be ensured that by defining the respective design architecture requirements, the main function at the level above is fully fulfilled, and the respective functionality is covered.

A battery system should ensure efficient and safe operation over the lifetime of the battery or its respective application. Moreover, it should be capable of providing and accepting a specific amount of power over a certain time-period.

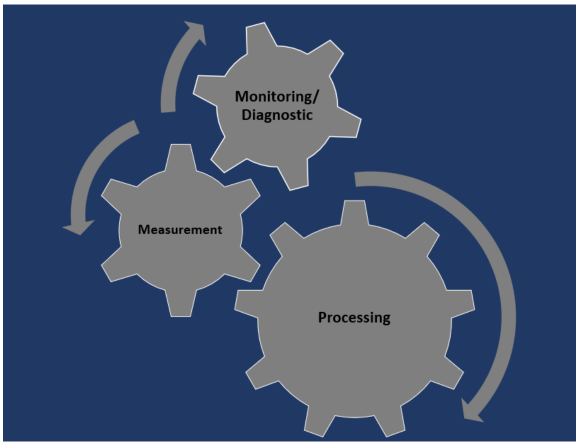

Figure 4: Interdependency of sub-functionalities to be covered to ensure the full functionality of main function.

The Electrical and Electronic (E/E) Architecture, which comprises several components, is responsible for this latter functionality. In Figure 5, a simplified technology independent battery system E/E Architecture including following main components, is shown [1]:

1. BMS Slave -Cell Controller Board
2. BMS Master,
3. LV and HV interfaces,
4. Fuses, contactors etc.

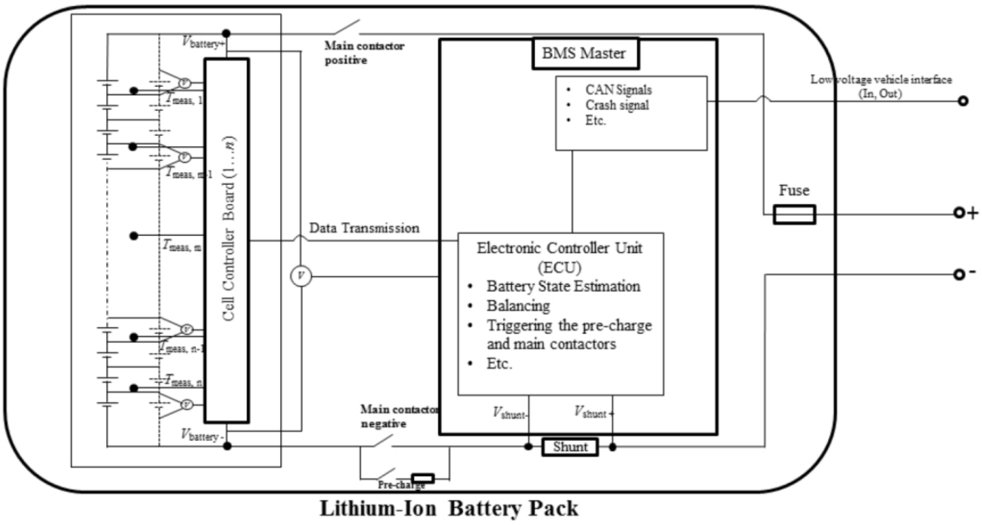

Figure 5: Schematic illustration of a battery system Electric and Electronic Architecture [1]

Summary

In this short blog, I have attempted to elaborate on the importance and background of a robust system architecture definition, using an automotive battery system as a reference. However, the main process of system architecture definition and its main functions remain mainly the same independent of the investigated application (with minor differences!). Even though the full complexity and content of such a work product cannot be fully encapsulated in a single article, I hope this has provided a useful introduction to the topic.

References

[1] A. Farmann, “Comparative study of reduced-order equivalent circuit models for state-of-available-power prediction of lithium-ion batteries in electric vehicles”, Ph.D. thesis, RWTH Aachen University, 2019, ISSN 1437-675X.