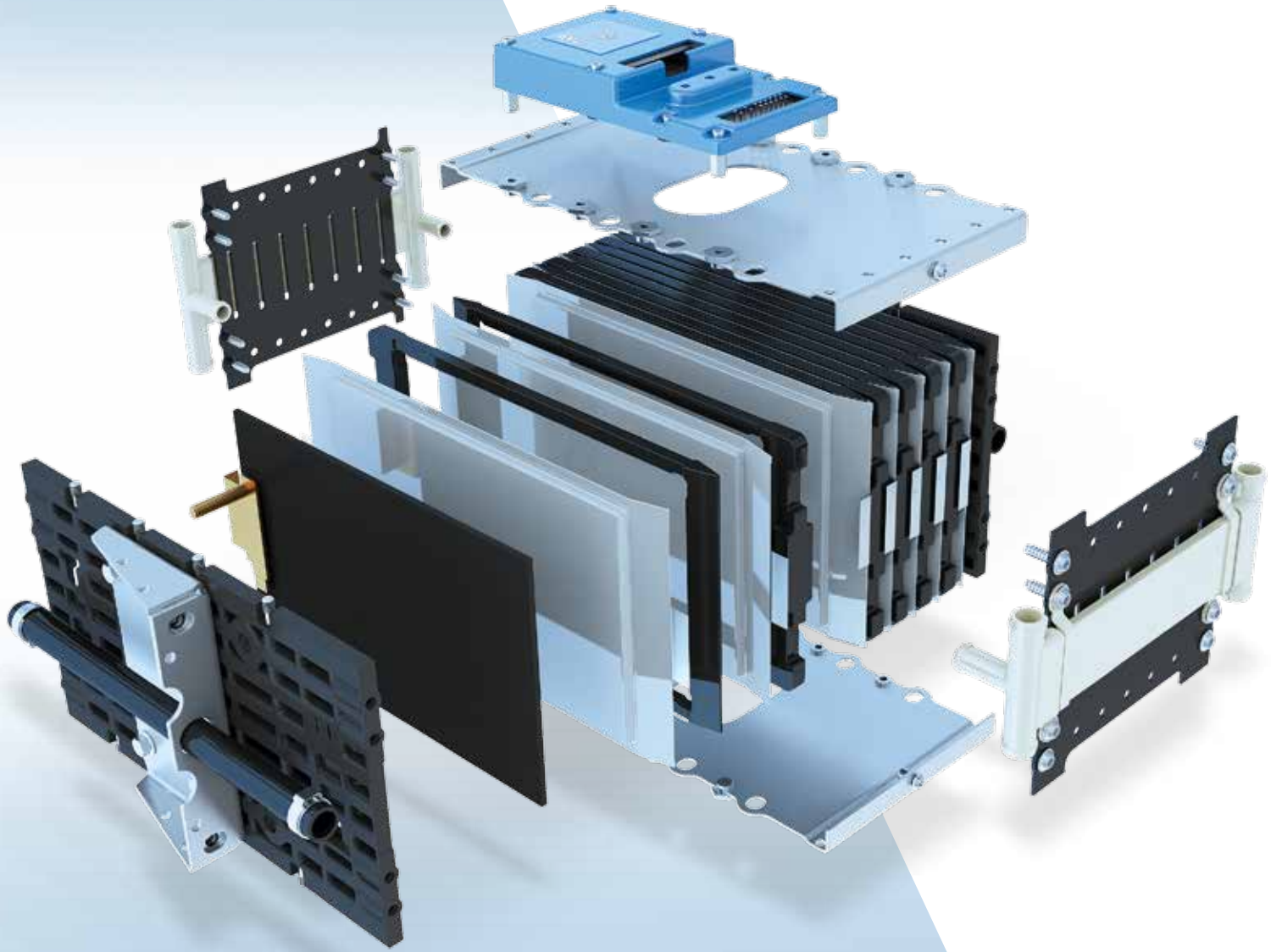
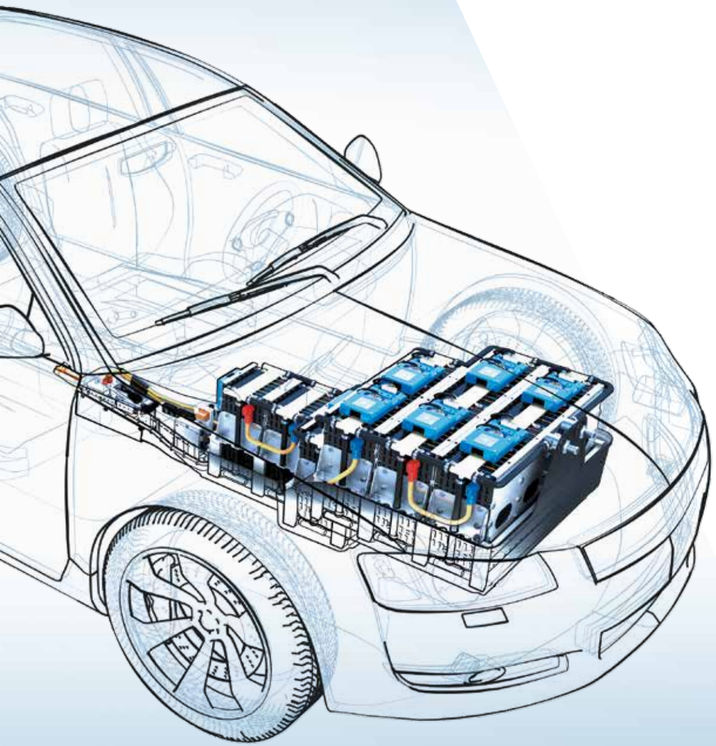
AVL Batteries

Engineering – Testing – System Integration





FIVE GOOD REASONS WHY TO CHOOSE AVL

At AVL we have a global passionate group of scientists, engineers and technicians that work on batteries. In our network of battery labs and development centres we are developing battery test equipment and the batteries for the vehicles of tomorrow.

- Competence for the whole powertrain
- Customer oriented solutions
- Robust and reliable design for mass production
- Global Project Execution & Support
- Testing equipment and expertise

Battery Solutions for Engineering and Testing

MARKET REQUIREMENTS

E-Mobility is a rapidly moving topic that requires highly professional solutions. Standards, regulations, market requirements and customer expectations are changing quickly. Thus, durable and reliable batteries are required to satisfy those needs and expectations.

AVL APPROACH

As a privately owned company, AVL is always operating independently and hence has access to different cell and battery technologies and is not limited to a special chemistry or cell design. With our global battery team we have the possibility to support battery projects around the world.

We take care of the most important topics in the development of tomorrow's batteries. The focus on a dedicated range of services and products allows the development of batteries from the assessment and selection of a single cell up to SOP of a fully validated battery pack.

While focussing on electrical performance as well as on mechanical and thermal integration of the pack into the vehicle, the overall cost of the battery at volume production stage is always considered. As of today, questions regarding the technology are in everyone's focus, but low cost design, serviceability and recyclability become more and more important as the e-mobility matures.

Left: Cell testing equipment in AVL's R&D lab
Right: Infrared image of cell

AVL'S PRODUCT PORTFOLIO FOR BATTERY DEVELOPMENT AND TESTING

A variety of highly instrumented cell and battery test-beds allows us to test and benchmark the full range from high power and high energy cells up to full battery packs with 500 kW power.

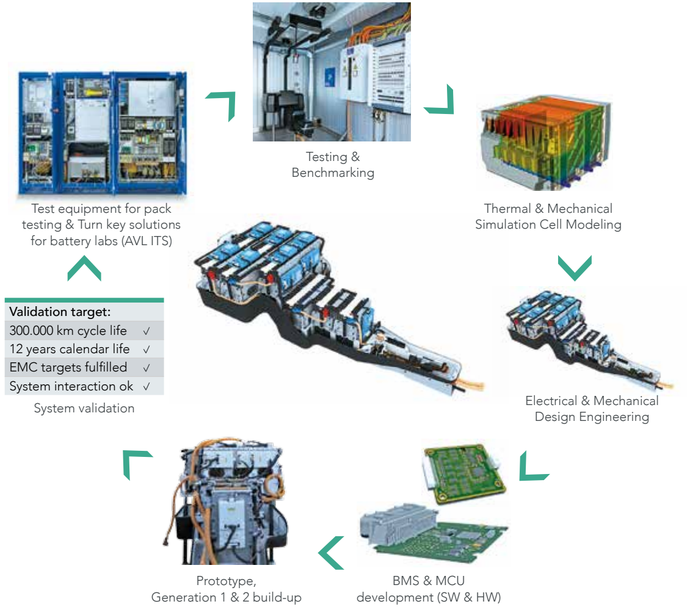
All electrical and thermal parameters that are obtained by advanced cell measurements are used to parameterize our dedicated electro-thermal models for best thermal performance of batteries.

Battery design experts take care of all mechanical and electrical integration aspects and make sure that the design meets volume production requirements.

AVL's proprietary battery management system assures a safe operation of the battery pack according to ISO 26262 while maximizing the battery performance.

With battery experts and a dedicated methodology in the field of reliability, durability and validation, lifetime and warranty targets are assessed.

All expertise in the field of battery development helps us to develop advanced solutions for battery testing and emulation (AVL E-Storage Tester™ and Emulator™). Furthermore we deliver turn key solutions for entire battery labs to our customers.



Testing & Benchmarking

CELL TESTING AND BENCHMARKING

Technology improvement of energy storage systems is progressing very fast. To keep up with latest technology advances of electrochemical energy storage devices AVL is continuously assessing the latest developments in the field of high energy and high power cells.

Based on a dedicated test program it is determined which cell technology matches best the targeted application (e.g. racing, passenger cars (e.g. HEV, PHEV, EV) commercial vehicles, off-road, stationary, etc.) and how it can be ranked in the market.

AVL's cell testing facilities are equipped with high-tech state-of-the-art equipment. Voltage levels from 6 to 20 V allows also tests on 12 V VRLA and lithium ion systems for soft & mild hybrids. Currents up to 800 A allow high power and cold cranking tests for all chemistries.

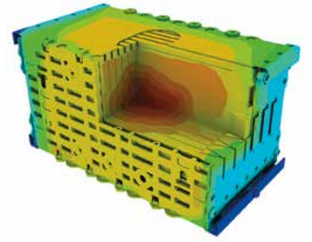
Regarding the equipment AVL is prepared to test everything from basic test routines defined in standards up to complex measurements with highly instrumented tests including thermal imaging.

BATTERY PACK TESTING AND BENCHMARKING

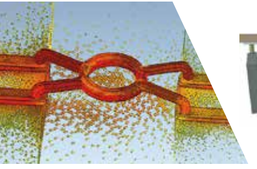
Dedicated test benches with up to 500 kW & 1,000 V optimized for a variety of validation tests and development testing are available at AVL. All sizes of battery packs up to 10,000 l can be tested in special climatic chambers. Closed-loop testing with an integrated battery management system and thermal conditioning (air, liquid, R134a) of the battery pack is our strength. Specific tests with more than 200 additional measurement channels for temperature, voltage, flow rate, pressure, current (all insulated up to 1,000 V) are available.

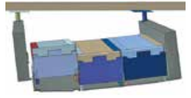
Benchmarking of battery packs with a focus on electrical and thermal performance, reliability, durability, cost and electrical components is done by our experienced battery experts.

High Perfomance EV and Racing requirements can be fulfilled by our test chambers



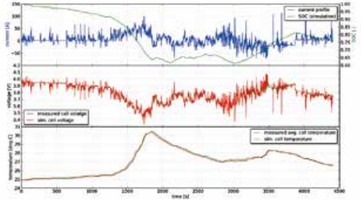
AVL Coup-e 800V module thermal simulation





Crash simulation for Batteries

3D EMC component simulation



1D Model thermal electrical model verification against measurements

EMC, Thermal & Mechanical Simulation

THERMAL ASPECTS

The strong temperature dependency of major characteristics of electrochemical energy storage devices requires an advanced thermal integration. Thus at AVL a standardized CAE engineering process for battery and electric vehicle thermal management analysis is established to assure power availability and a long battery life.

A consistent testing procedure for electrical and thermal characterization of a cell creates a basis for model parameter identification and model validation. Cell Model development and validation is done with an AVL developed software tool for cell model parameter identification and 0D model validation.

For best conformity of all simulation results a continuous simulation approach is chosen. One standard solution using the same model for 3D electro thermal performance simulation and 0/1-D vehicle energy management simulation with AVL Cruise is established.

Precise models allow us to optimize the thermal integration of cylindrical, pouch and prismatic metal can cells. Thermal conditioning (cooling/heating) requirements for the battery pack and the vehicle are derived. Furthermore minimum and maximum cell temperature during operation and parking can be assessed under given boundary conditions.

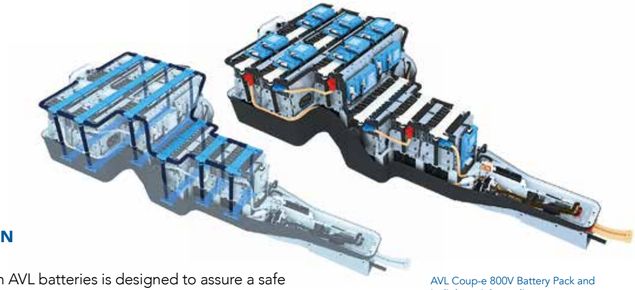
MECHANICAL ASPECTS

A suitable mechanical integration of the cells assures safety of the battery pack under all conditions. Cell swelling over life, tightness of the gasket, mechanical integrity of the modules, crash acceleration, torsion, stability of the housing, etc. are topics that are intensively investigated using FEM simulation.

EMC ASPECTS

A considered design for electromagnetic compliance enables fault reduced operation of the vehicle and a safe and healthy environment for the passengers. Simulation of components in 3D yields design recommendations as well as basic models for system level simulation of electromagnetic emmision and grounding concepts.

Battery Design Engineering & Battery Build



AVL Coup-e 800V Battery Pack and its light weight cooling system

MECHANICAL DESIGN

Mechanical design has significant impact on the volumetric and gravimetric energy density of a battery pack.

Sophisticated approaches are required to leverage the entire potential of electrochemical cells. Precise simulation results identify and help to optimize the most appropriate thermal conditioning system for the application.

Pack design also addresses key requirements for volume production like manufacturability, serviceability and recyclability in an early stage of the development process.

AVL is your partner for the development of battery packs. Our experience in batteries enables us to develop tailored battery packs up to SOP in various application fields.

To assure our customer's freedom to operate AVL secures a good IP base in the field of batteries covering various aspects (battery monitoring system, module design, cell to cell connection, cooling concepts, retention, etc.).

ELECTRICAL DESIGN

The electrical system in AVL batteries is designed to assure a safe system behavior over the entire current range from zero amps up to a short circuit incident.

System know-how and detailed understanding of the functionality of all electrical components inside the battery pack are therefore mandatory skills. AVL assures compatibility of all electrical components under all conditions, hence unrestricted operation under all conditions can be guaranteed. Furthermore highly skilled EMC experts support the electrical design and layout to minimize electromagnetic interference.

BATTERY MODULE AND PACK ASSEMBLY

Battery pack development requires the ability to build up modules and packs for validation and testing. Dedicated areas for battery assembly and analysis as well as a prototype workshop allow quick build up and modification of batteries. Ease of assembly is assured by early involvement of specialists in the field of automated battery assembly. Thus our optimized design guarantees manufacturability and brings down assembly costs.

Battery Management System (BMS) Development

BMS SYSTEM OVERVIEW

AVL's BMS was designed to be a flexible platform for battery development on HEV, PHEV or EVs. The BMS is a distributed system with the battery control unit (BCU) as the master and module control units (MCUs) as the slaves. The system is capable of voltages up to 800 VDC. The BMS balancing system can either be passive or active.

HARDWARE

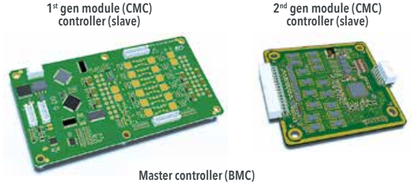
The BCU uses a 32-bit microcontroller with a wide variety of I/Os to manage and communicate with various sensors and actuators as well as to interface with the module control units. The BCU supports up to 3 CAN networks which are typically used for (1) vehicle communication, (2) internal CAN between BCU and MCUs and (3) optional CAN for such items as instrumentation CAN or service CAN. There is also a redundant digital synchronization and fault circuitry for BCU/MCU network safety monitoring.

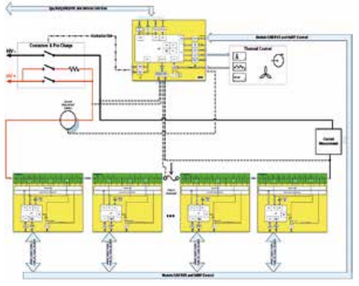
The MCU is an 8-bit controller that supports up to 12 cells in series. The MCU senses cell voltage (every cell) and temperature (up to 4 temperatures per module) and reports these values to the BCU.

SOFTWARE FUNCTIONS

The in-house developed BMS software comprises basic and application layer software. Many functions are model based. Supported functions include:

- State of charge (SOC)
- State of function (SOF)
- Stage of health (SOH)
- Balancing
- Cell failure detection
- Signal acquisition
- Actuator control
- Contactor control
- Pre-charge function
- Startup/shutdown
- Charger communication
- Thermal management
- Isolation detection
- HV-interlock
- Safety monitoring
- Diagnostics (OBD, service)
- Error management
- CAN and service tool communication





AVL BMS System overview

Battery System Validation

Current batteries are a young technology for the automotive industry. This poses a significant risk for the battery supplier and the OEM regarding warranty and service costs and also can jeopardize the market reputation.

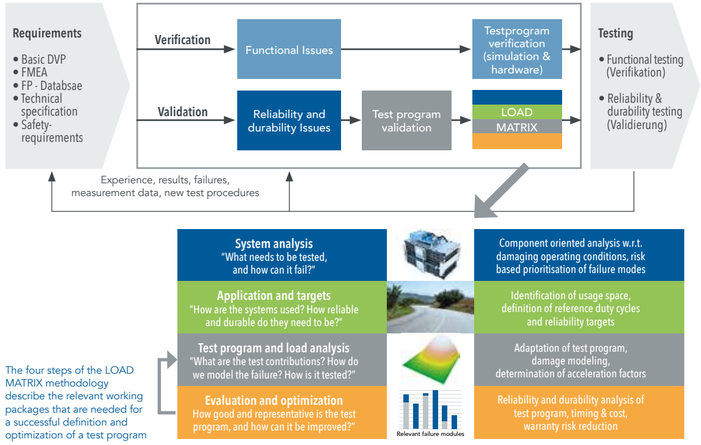
In order to improve this situation, AVL is focusing on validating the vehicle battery for the entire lifetime based on suitable and efficient methods.

To reduce cost and time for such an evaluation AVL has developed the LOAD MATRIX® method to assess the durability and reliability potential of complex systems like batteries.

Appropriate methods for an improved validation have to cover the following key topics:

- Analysis and characterization of key issues of the used battery technology
- Clear definition of durability and reliability development targets
- Clarification of customer usage profiles for battery specific topics
- Precise structuring of testing activities at OEM and suppliers
- Demonstration of actual development status, resulting risks and required optimization steps for all involved development partners
- Methodology of test and parameterization of damage models for batteries and cells of different chemistries
- AVL Reliability Monitoring is a quantitative assessment of product reliability, as well as a basis for supplier management, reliability target allocation and warranty cost monitoring.

Design Verifications & Validation Plan (DVP)



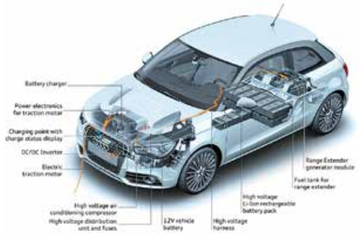
The four steps of the LOAD MATRIX methodology describe the relevant working packages that are needed for a successful definition and optimization of a test program

Low-cost 48V battery technology demonstrator

Solutions for Racing, Passenger- & Heavy Duty Vehicles
12V - 48V - 150V - 400V - 900V

Electrification of passenger cars is no longer a trend but already a fact. Thus, affordable, vehicle integrated, robust and reliable batteries are a must for the successful commercialization of electrified vehicles. AVL develops both high energy and high power battery packs for any kind of hybrid and full electric vehicles.

AVL addresses the variety of required technical and affordable solutions by a modular concept and a flexible development process of the battery pack. Since AVL is not a cell manufacturer we can select the most adequate cell technology (both cost and technology wise) for different applications.



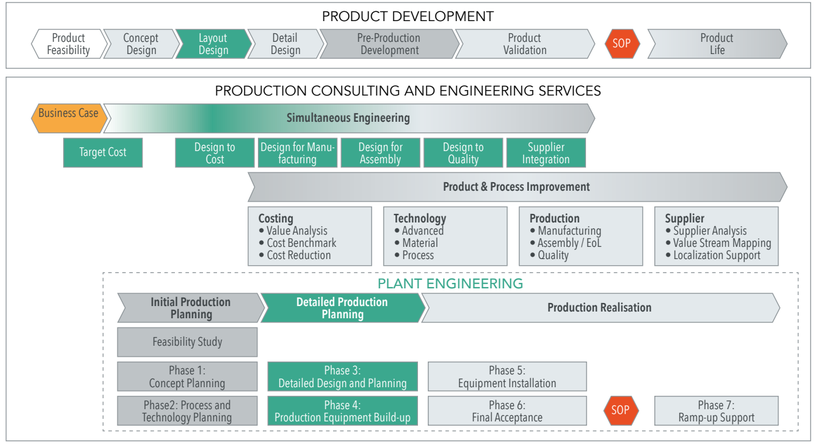
KAMAZ Battery Electic Truck by AVL

Beyond providing prototype and series intent batteries to our customers, we support them on-site during vehicle integration. For battery pack series development AVL also has profound knowledge in production engineering for manufacture.

Production Engineering for Batteries

AVL's Plant and Production Engineering for Batteries encompasses services that cover the entire product life cycle. In the design phase, aspects of manufacturability and costs are systematically incorporated. Optimizing and improving the productivity of manufacturing processes including the analysis of quality problems is another thrust of AVL's portfolio.

Our solutions include a supplier development program, which ensures that the customer receives the right product at the right time. The main objectives are reduced costs, improved quality and improved delivery performance.



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