Battery Cell Anomaly Detection via IAV Virtual Battery Testbench based on COMSOL® API

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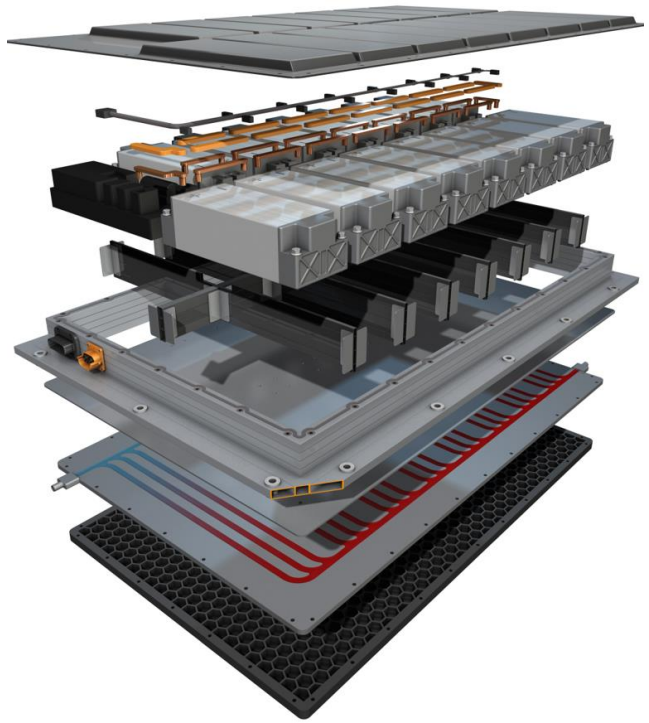
IAV Battery Development

- Concept Development
- Serial Development
- Integration & Calibration
- SoP
- EoL



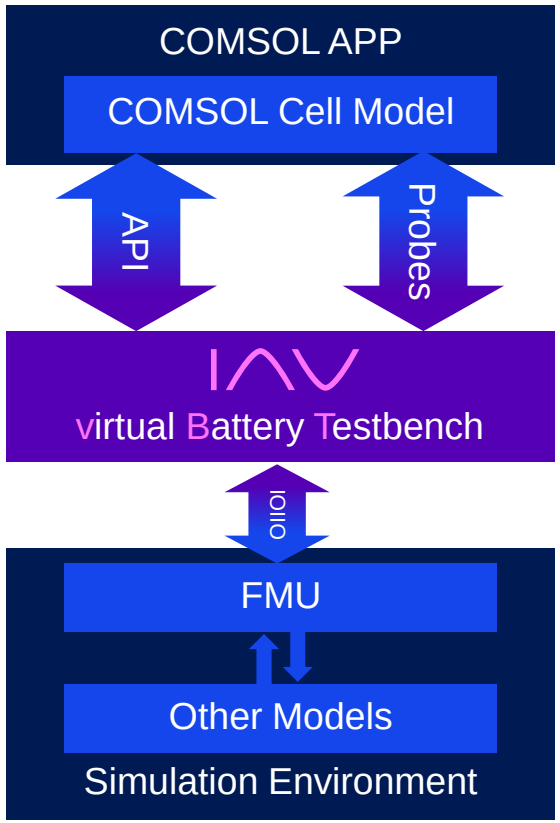
- Simulation
- New Cell Chemistries
- Thermal Management
- Fast Charging
- BMS HW & SW using AI

More then 30 years of experience in EV & battery development

Over > 1,000 EV & battery specialists

Providing tech solutions worldwide at 24 locations

Virtual Development



Battery expert

- Broad expertise in battery cell modelling
- Model distribution to specialists in other fields
- Uses COMSOL Multiphysics® and COMSOL Compiler™
- Other models (e.g., GT Autolion™, PyBAMM) can also be used

BMS / thermal management / vehicle experts

- Can run parallel calculations within their usual tool chains and developing environments (e.g., INCA-FLOW™, GT-SUITE™, SIMULINK® etc.) without the need of a COMSOL license.

Virtual development is the key to achieve the needed reduction of time and costs for the development of electric vehicles

FMU: Functional Mock-Up Unit
API: Application Programming Interface
SOC / SOH: State of Charge / Health

Timeline for Thermal Runaway and Propagation

Production

Controlling of process, material and final product. Elimination of faulty or problematic cells through quality management.

Early Detection

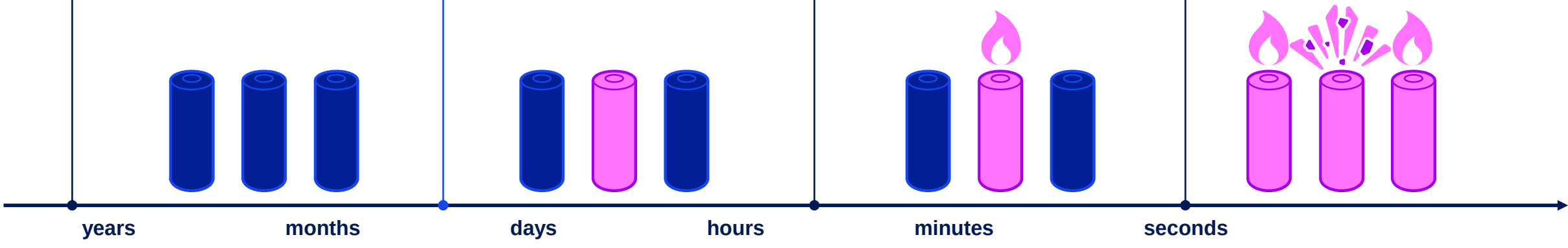
Internal changes and strange behavior of cell voltage during idle and runtime. External signals usually undetectable.

Detection

Detection of increased temperature (internal and/or external). After Point of no return exothermic reactions exceed cooling capacity.

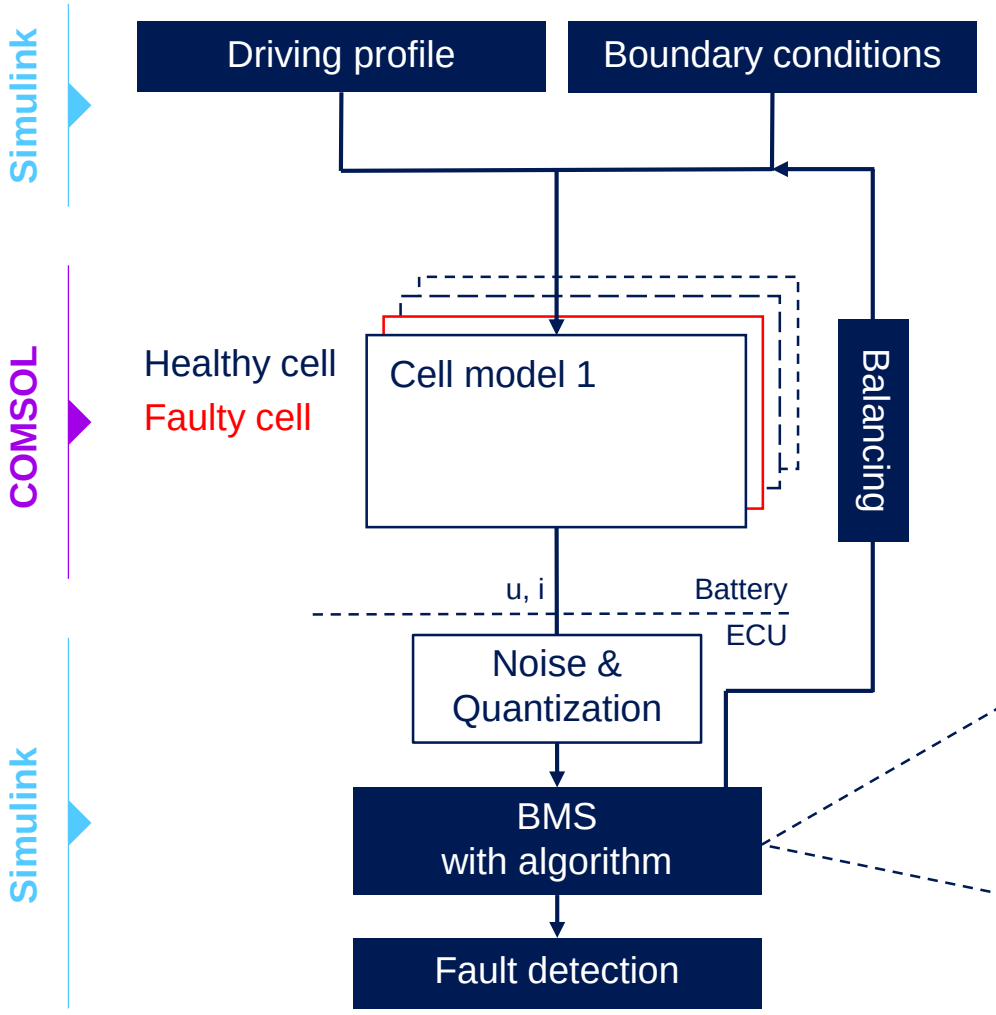
Propagation

Heat generation during thermal runaway high enough to propagate on neighboring cells. Only drastic solutions capable to prevent spreading or damp event.



Early detection of cell anomaly supports preventing catastrophic battery scenarios

Anomaly Detection – Overview Approach

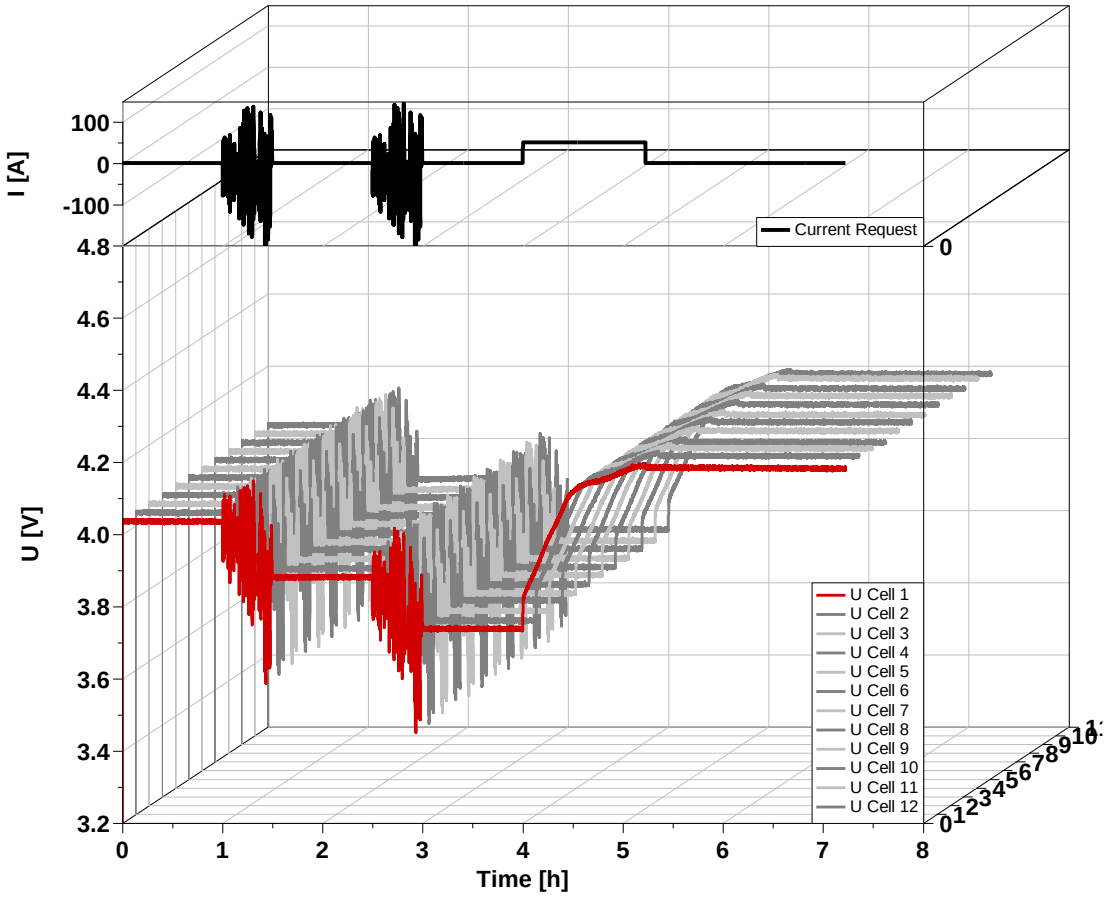


- The cell model is abstracted to JAVA code and compiled into a **COMSOL App**
- Balancing function applies shunt to corresponding cell

Fault diagnosis methods

Analytic model based	Signal processing based	Knowledge based
Parameter estimation • **Recursive least squares** • Filter	Transformation • Wavelet • Fourier	Machine learning • **Random forest**
State estimation • Kalman filters • Luenberger observer	Correlation analysis • Correlation coefficient	Fuzzy logic
Parity space • Nonlinear parity equations	Entropy • **Shannon**	Neural networks

Anomaly Detection – Overview Input



Model set-up

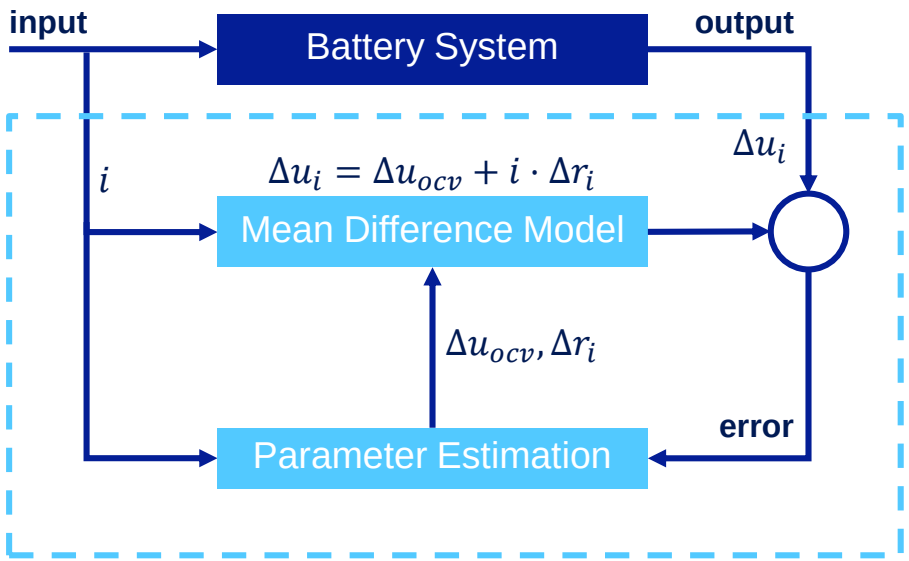
- Current profile contains idle, driving and charging phases
- 12 cells, NMC811 chemistry, 12s1p configuration, 78 Ah, initial SOC 80%
- Cell models in COMSOL APP feature adjustable statistical differences in capacity and state of aging
- Variation of cell parameters:
  - Healthy cells R_{isc} either 10,000 or 1,000,000 Ω; faulty cell R_{isc} is 100 Ω (●)
  - Cell capacity scales between ± 2%
  - Cell film resistance scales between ± 5%

Voltage signals of cells with varying R_{ISC} not distinguishable without application of algorithms

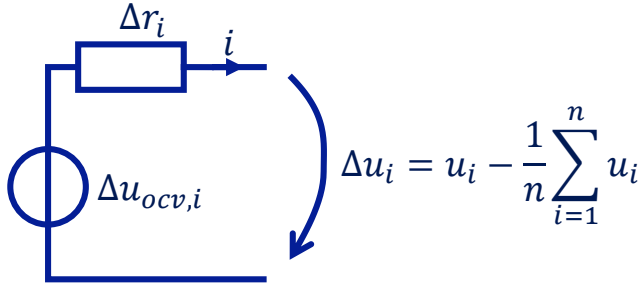
SOC: State of Charge

R_{isc}: resistance of the internal short circuit

Anomaly Detection – Recursive Least Squares Method

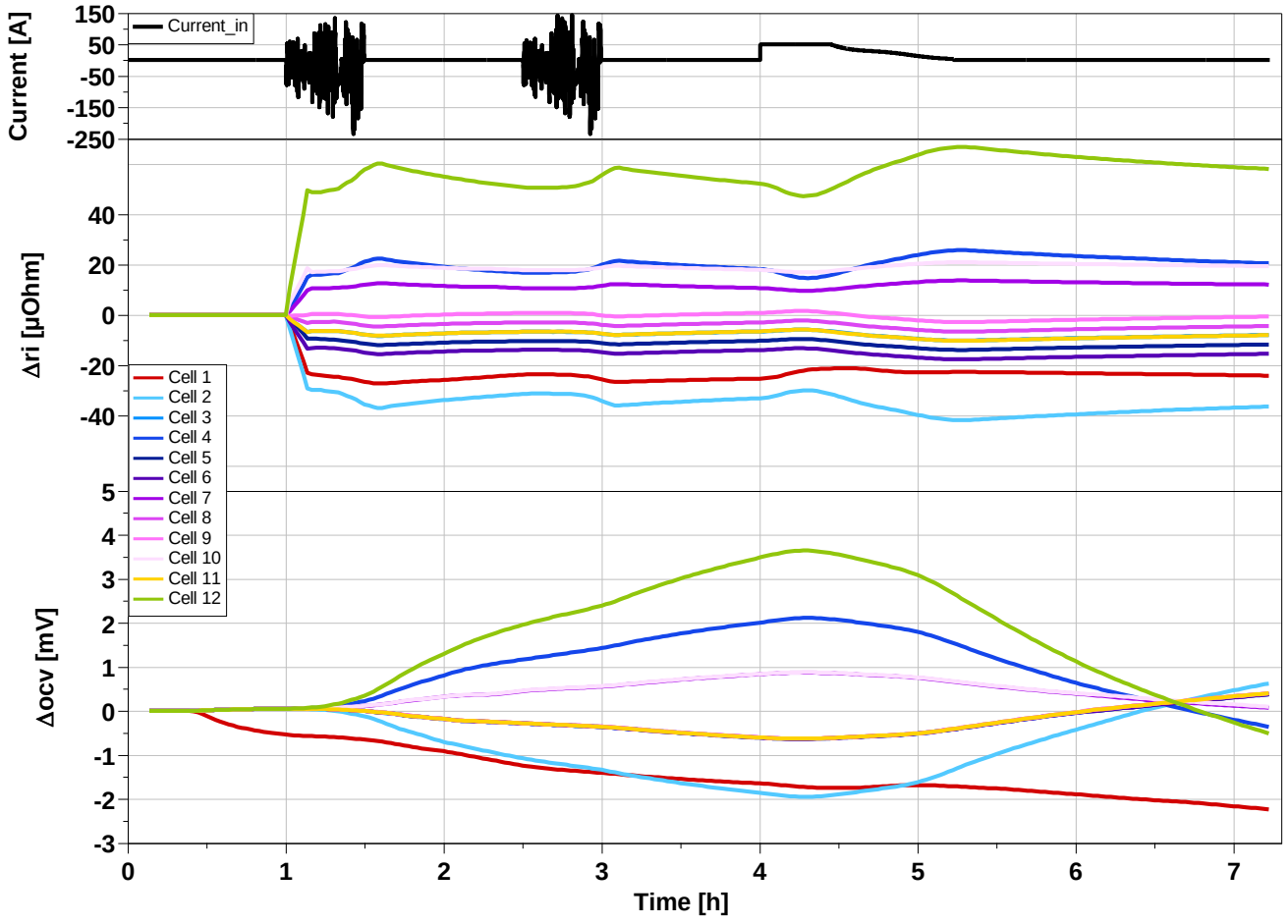


- Parameter estimation of Δu_{ocv} and Δr_i to **minimize error** between linear **mean difference** model (difference of each cell to mean value) and **measured values**



Parameter estimation depends on input (dynamic or steady state operation point)

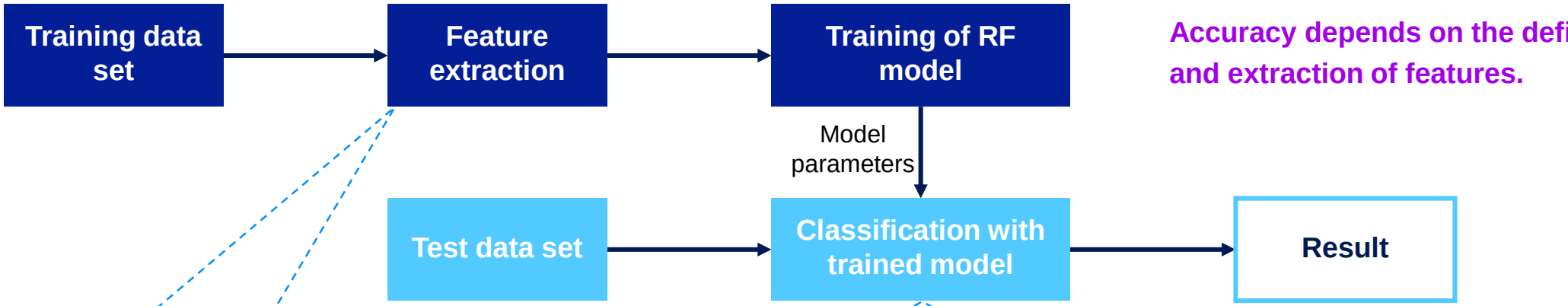
Anomaly Detection – Recursive Least Squares Method



Results

- Estimated parameter of Δu_i and Δr_i for all 12 cells are shown
- Δr_i: cells with high and low capacities (● ● ●) detectable as outliers
  - Small influence of the low R_{isc} (100 Ω) for the faulty cell (●)
- Δu_{ocv}: cells with high & low capacities (● ● ●) **and faulty cell** (●) detectable as outliers
- Continues self discharge due to low R_{isc} for faulty cell detectable as permanent deviation of measured and estimated Δocv value (●)

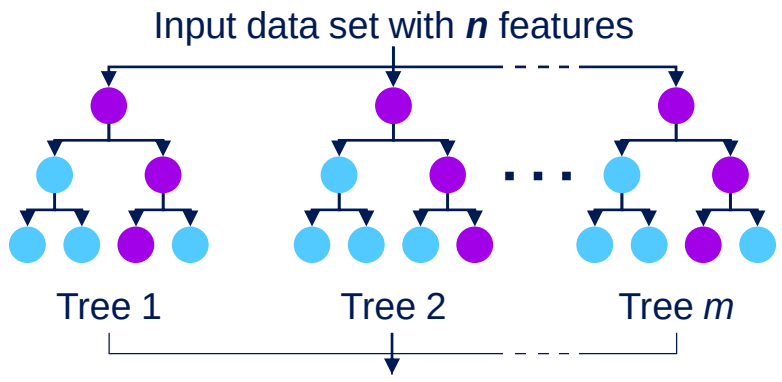
Anomaly Detection – Random Forest Classification Method



Accuracy depends on the definition and extraction of features.

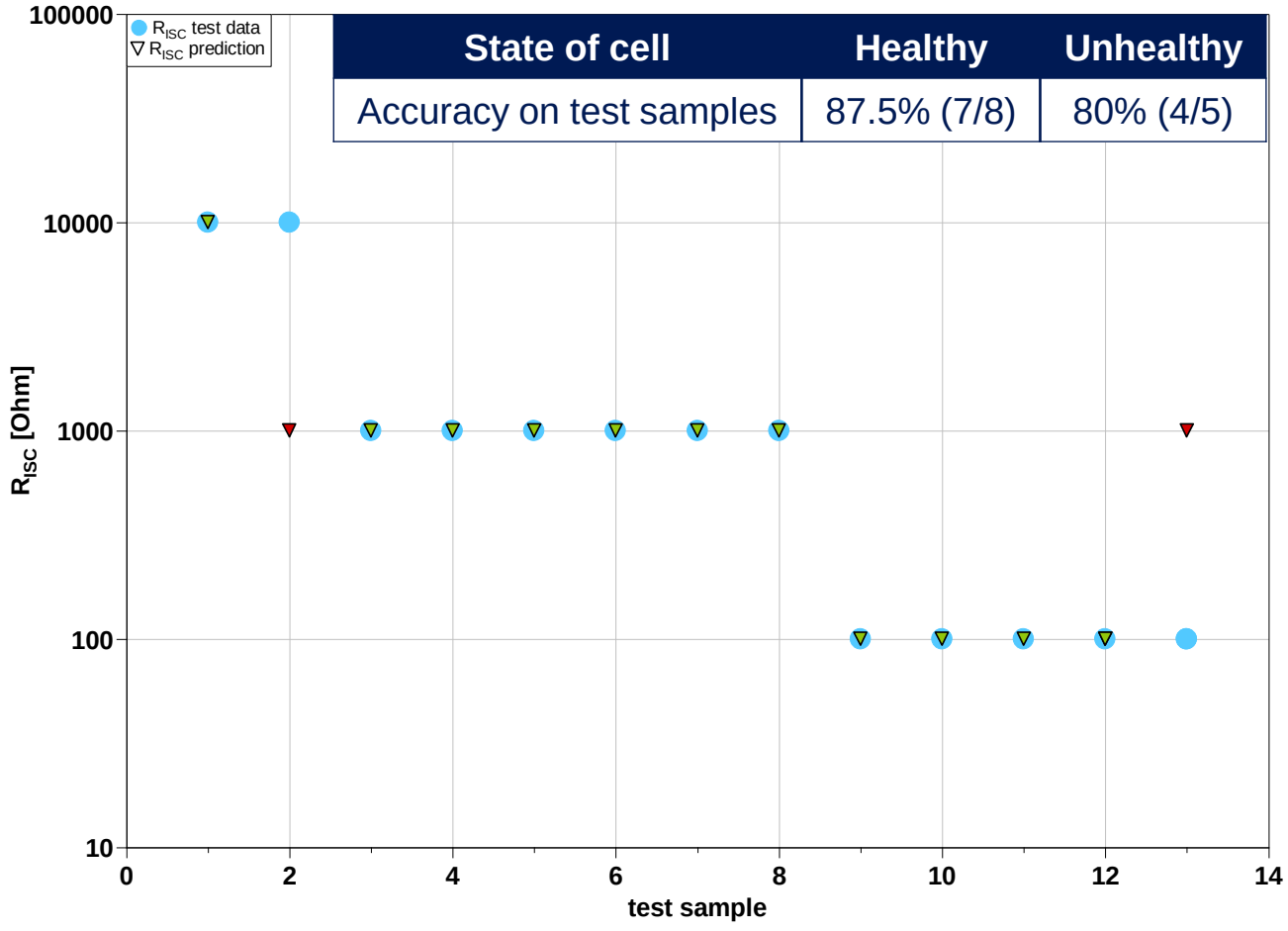
Selected Features:

- Energy loss during discharge and charge cycle
- Change in equivalent resistance of the cell
- Voltage drop during idle time



Each tree uses a subset of ***n*** features

Anomaly Detection – Random Forest Classification Method



State of cell	Healthy	Unhealthy
Accuracy on test samples	87.5% (7/8)	80% (4/5)

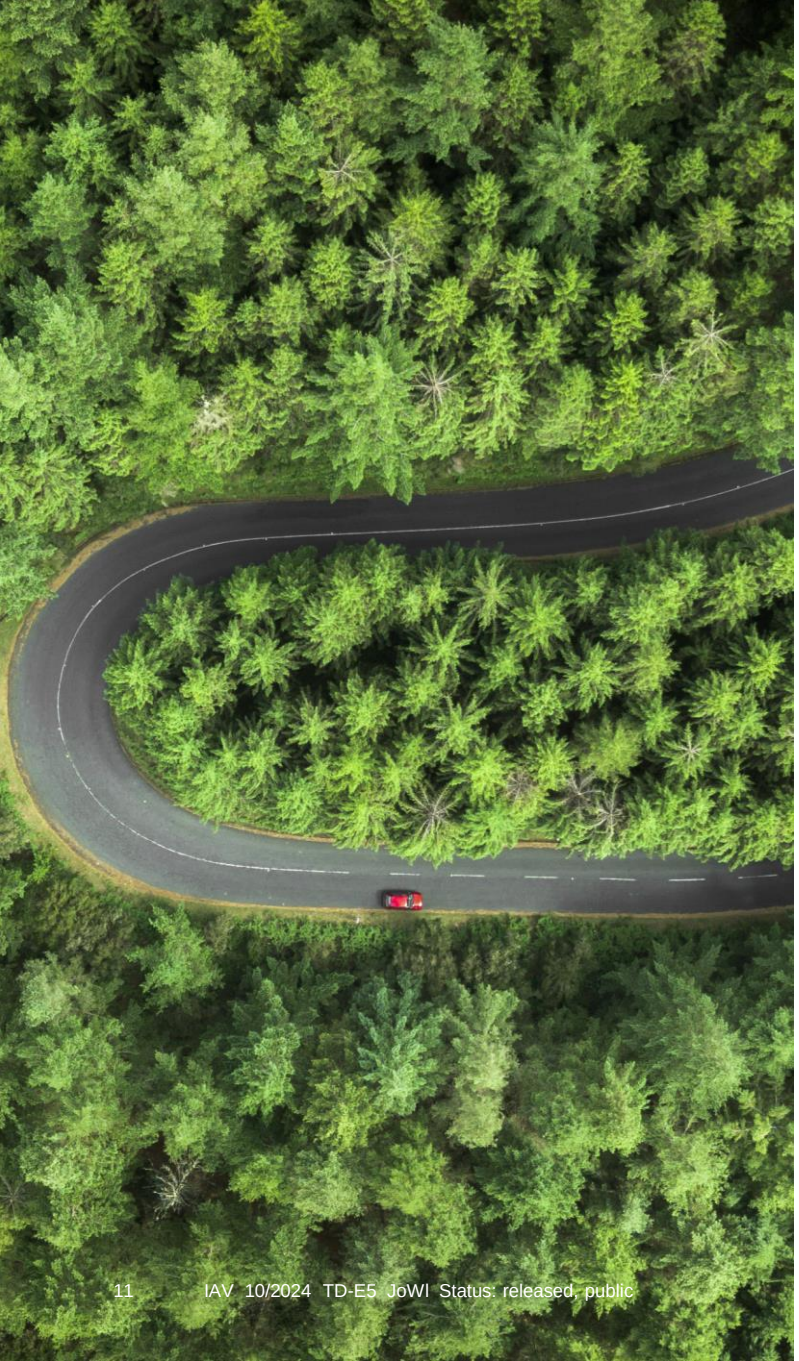
Adjustment of set-up (COMSOL model)

- Input of 52 cells → Adjustment of the model to increase number of cells
- R_{ISC} values of 100, 1,000 and 10,000 Ohm examined
- From available data 75% used for training, 25% as test data

Results

- Detection of faulty cells with low internal short circuit resistance (100 Ohm) mostly correctly classified

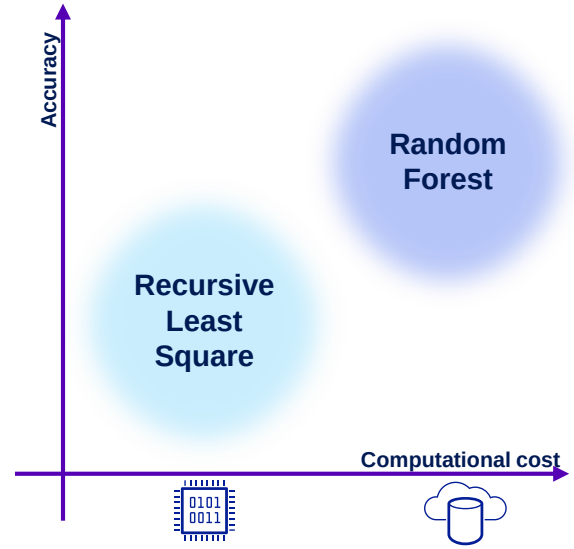
Despite small size of training data set, good accuracy for identification of faulty cells

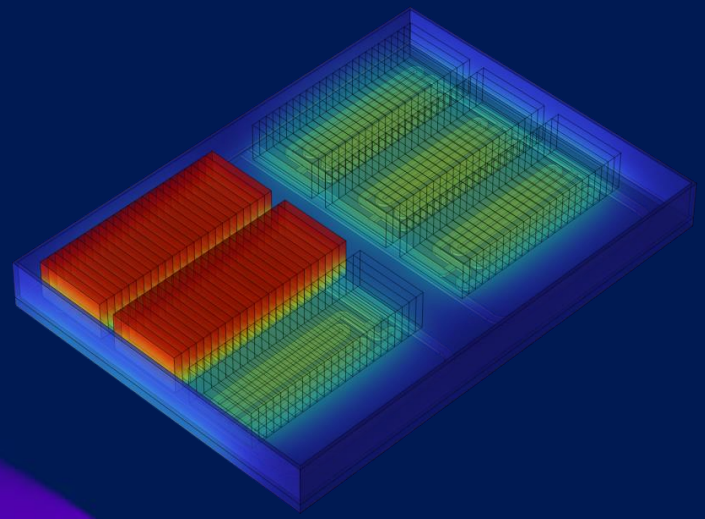


Summary & Outlook

- **Model-based approaches** are the key to achieve the needed reduction of time and costs in the development process of electric vehicles
- IAV has established a **holistic virtual development process** for batteries using COMSOL Application Builder in conjunction with COMSOL Compiler™

- The exemplary use-case of **cell anomaly detection** development was presented
  - Identification of cells with a low internal short circuit resistance via BMS-available signals
  - Signals of faulty and healthy cells were generated via cell models
  - Two different fault detection algorithms with different approaches were selected and compared (a third one is shown on the poster)





electrified by vision

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