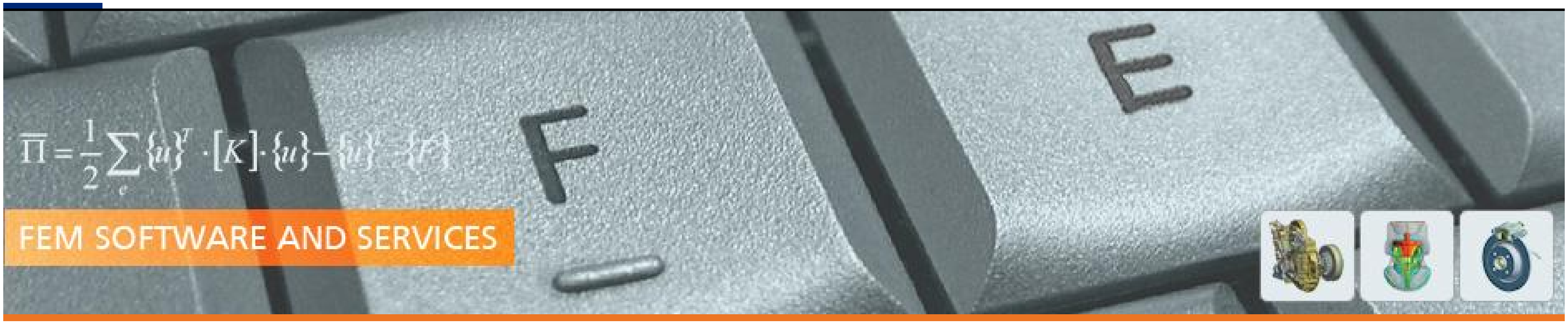

System Level Battery Thermal Behavior Study

Lucas Kostetzer

CADFEM / ESSS

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Scope and Objective

- Battery temperature under control means:
  - Optimal capacity
  - Optimal life
  - Safety operation

- Thermal phenomena coupled with electro-chemical
  - Heat generation: <u>Chemical Reaction</u> and <u>Joule Effect</u>
  - Heat transfer: Cooling by <u>convection</u> and conduction

- **The goal is:**
  - **To control the temperature in the battery pack**
    - **Battery ageing**
    - **Safety reason (explosion)**

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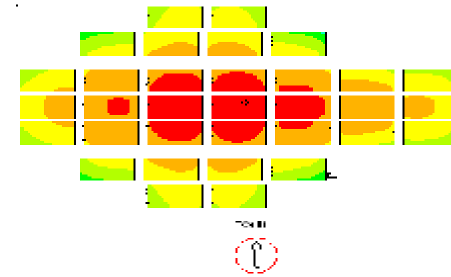
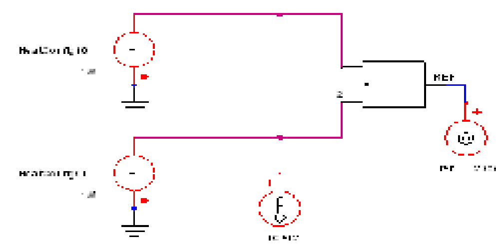
Approach

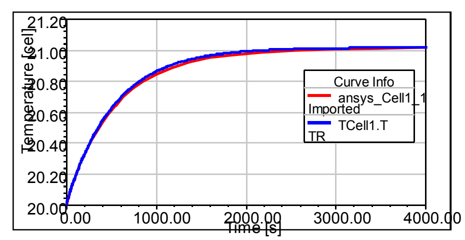
- **Device level thermal simulation**
  - ANSYS Thermal Model
  - Simulation of transient behavior of battery



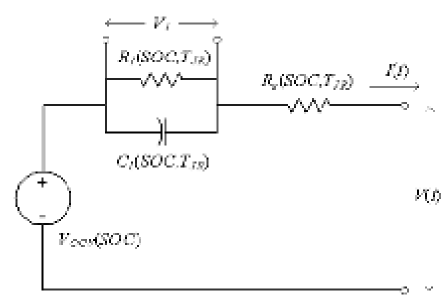
- **System level thermal simulation**
  - Simplorer Circuit Model
  - Thermal circuit model (reduced model) generated by MOR for ANSYS



- **Verification**
  - Compare results of reduced model with FEM model



- **System level Electric-Thermal simulation**
  - Include electric behavior model



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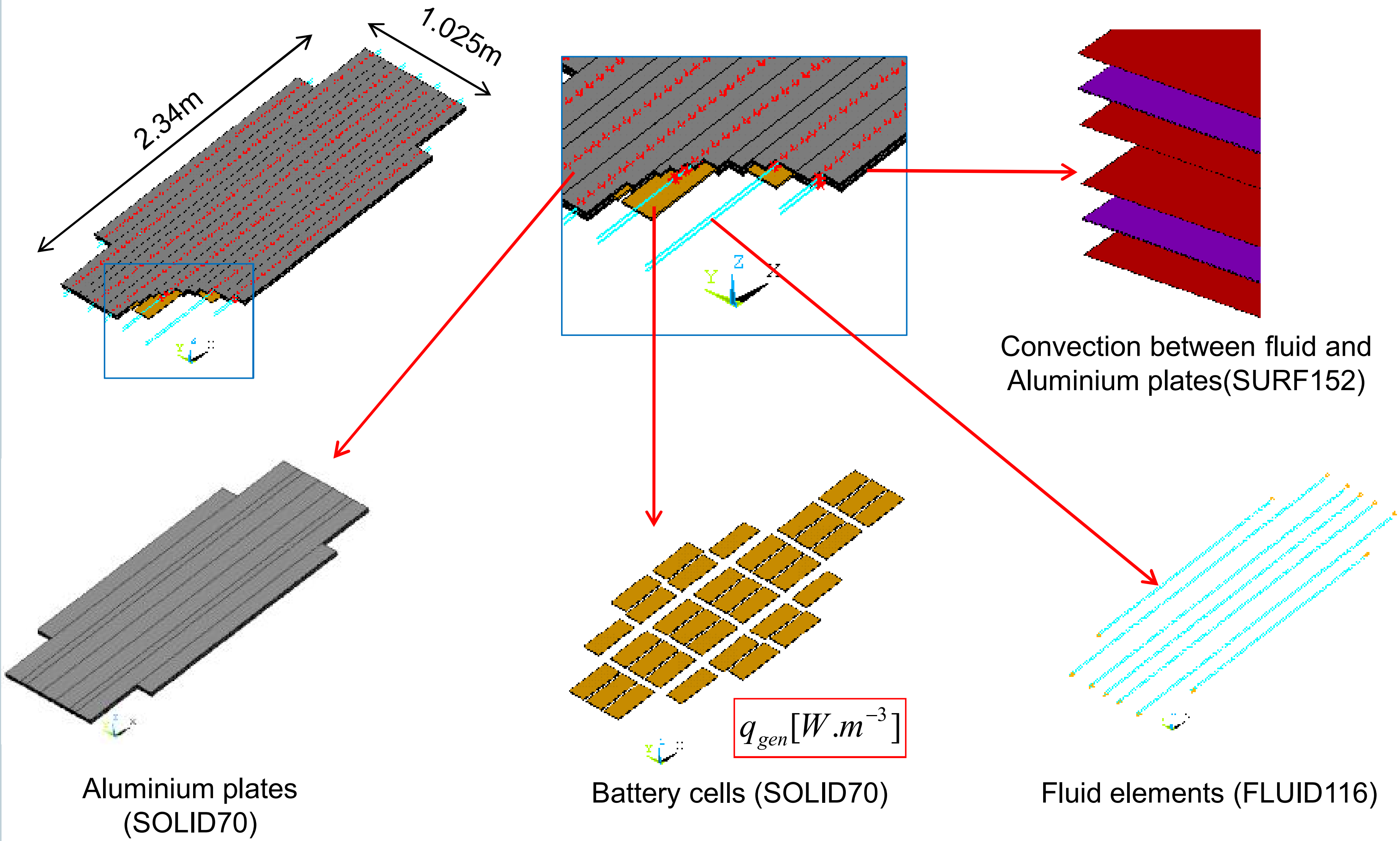
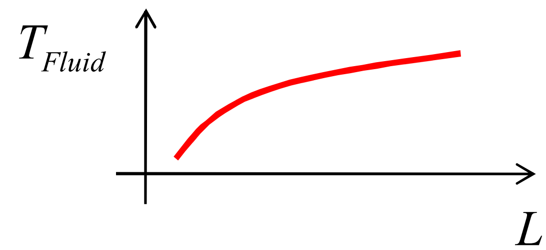
ANSYS Battery Model



Simplified CFD model - Air Cooling

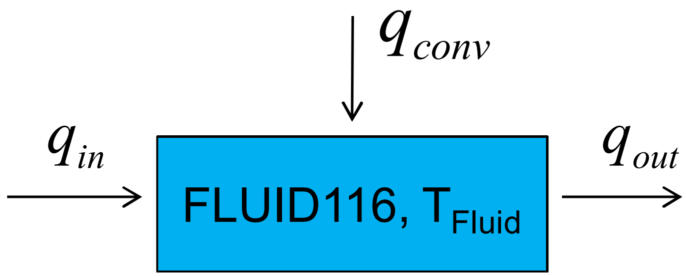
- Compute temperature rise of cooling air

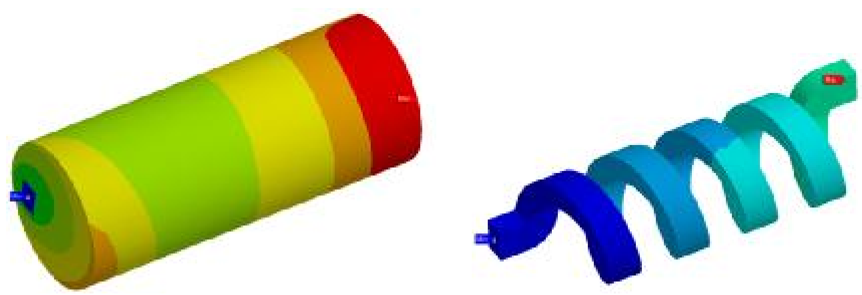


- Rectangular channel flow, D_h
- Simplified by 1D (FLUID 116)
  - DOF=Temperature

$$q_{conv} = h(T - T_{Fluid})$$

(SURF152)





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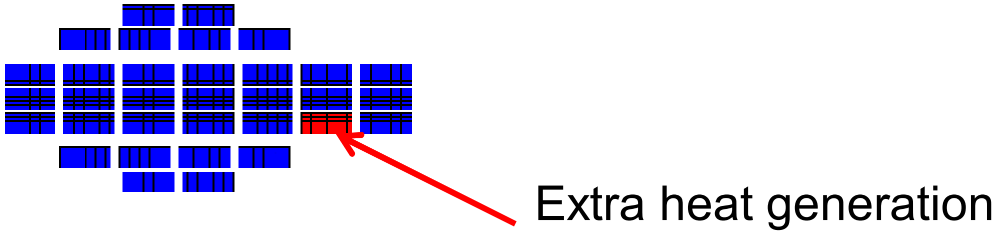
Case of Study

- The Battery pack working properly, but…..
  - ONE cell has an internal problem and generate extra heat !!

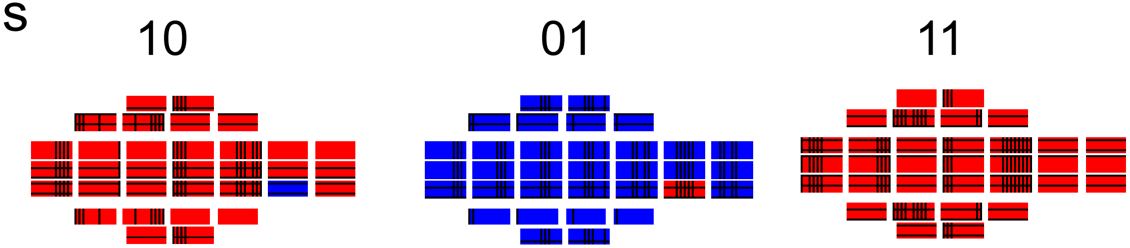


- Temperature has reached the operation limit?
- How is the temperature response of this cell?
  - And for the pack?
- If a new electrical load is applied ?

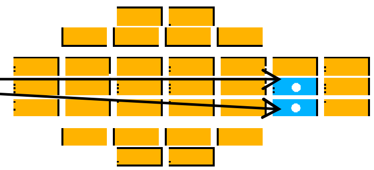
"Detailed" information with fast response is needed

Configuration – ANSYS and MOR

- Two Independent INPUTs
  - Heat generation
    - 1W /Cell



- OUTPUT
  - Temperature



Each cell can be modeled eg. 33 cells (no limitation)

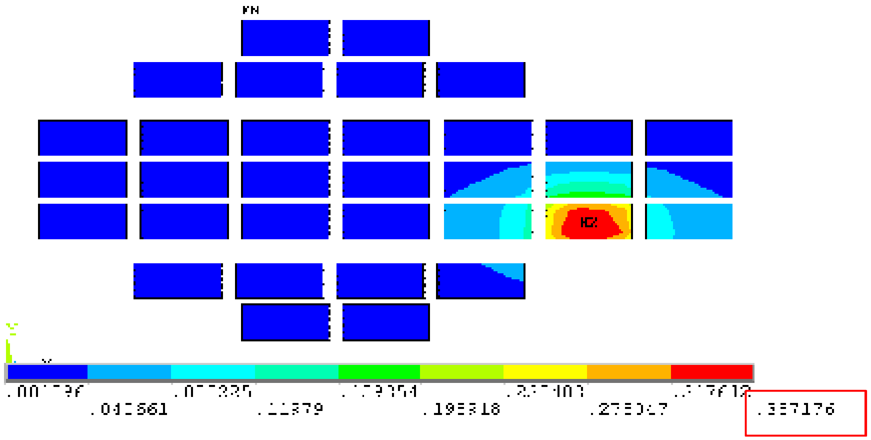
3 ANSYS models
11
01
10

MOR for ANSYS

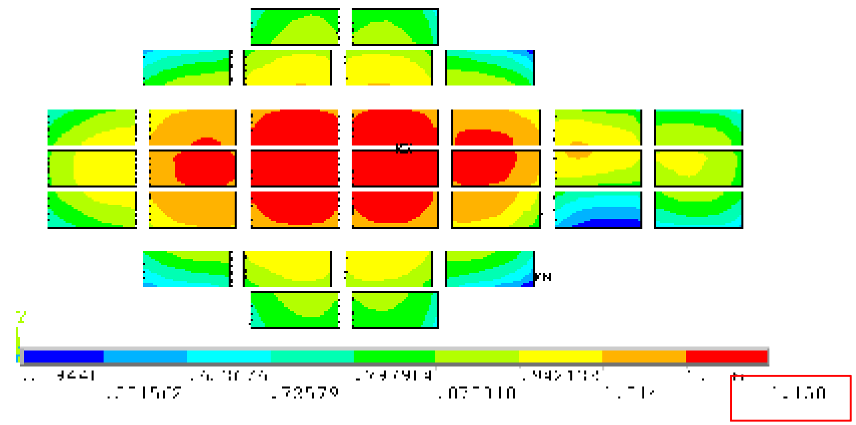
Reduced order model

<u>Independent of Input functions</u>
<u>Simulation not needed, just matrices</u>

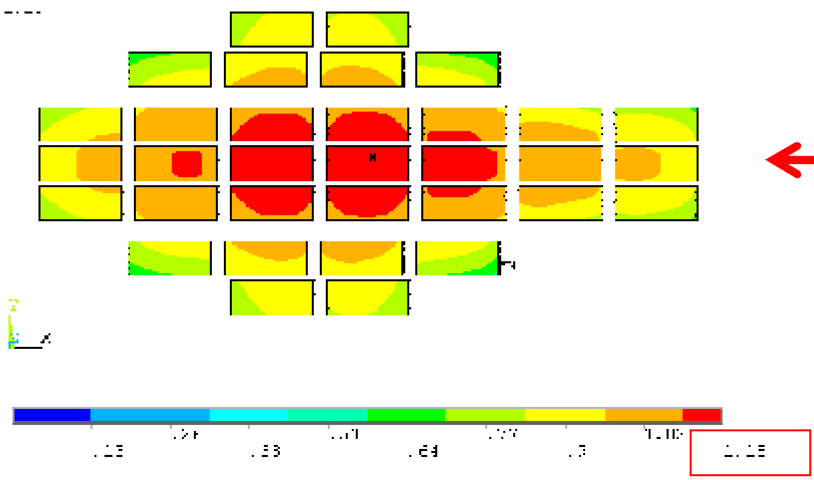
ANSYS Transient Thermal Battery Model



Load case 01 @ 4000 seconds



Load case 10 @ 4000 seconds



Load case 11 @ 4000 seconds

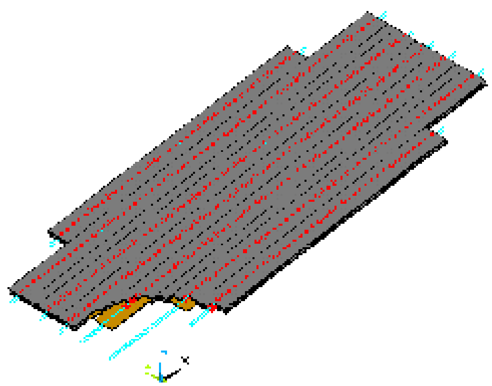
Selected for comparison with reduced order model

CADFEM

From ANSYS to Simplorer through MOR

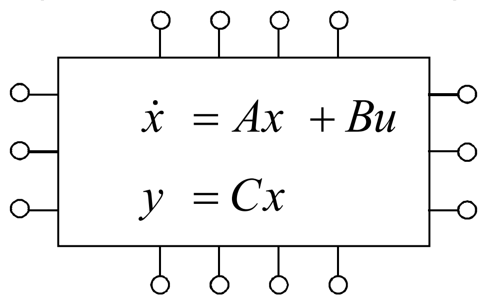
ANSYS matrices → **MOR** → Reduced Model → Simplorer

Complete FEM model

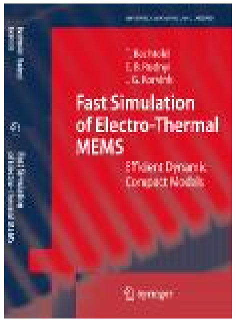


LIONSmart

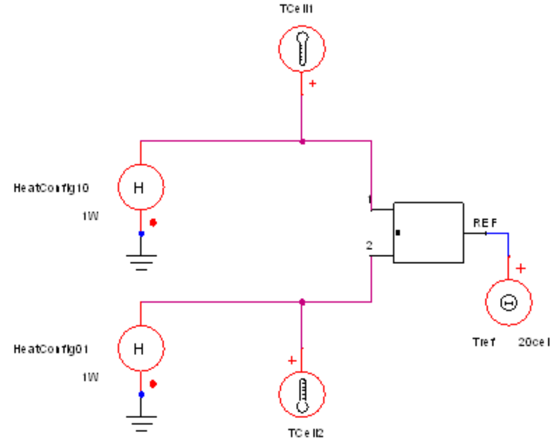
Reduced dimension
(State Space Model)



$$\dot{x} = Ax + Bu$$
$$y = Cx$$



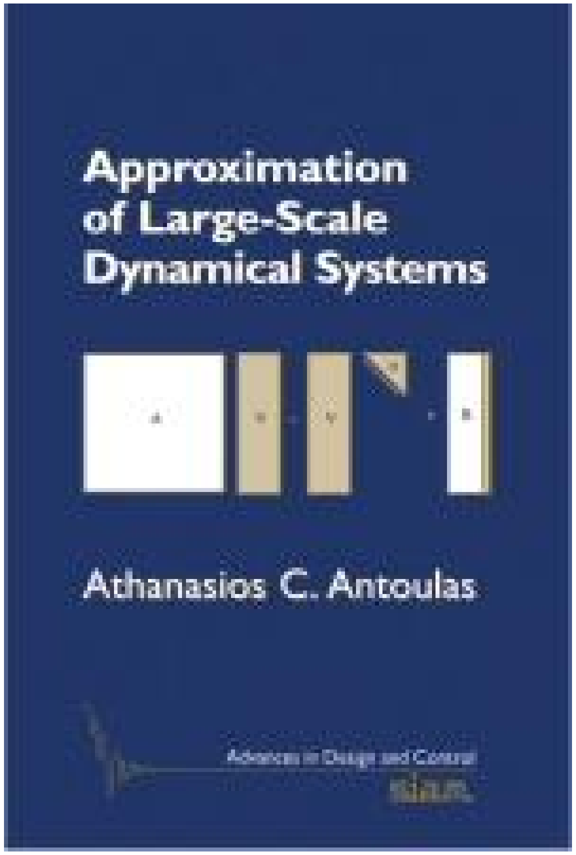
System level simulation



CADFEM

Model Order Reduction

- Relatively new technology
- Solid mathematical background:
  - Approximation of large scale dynamic systems
- Dynamic simulation:
  - Harmonic or transient simulation
- Industry application level:
  - Linear dynamic systems

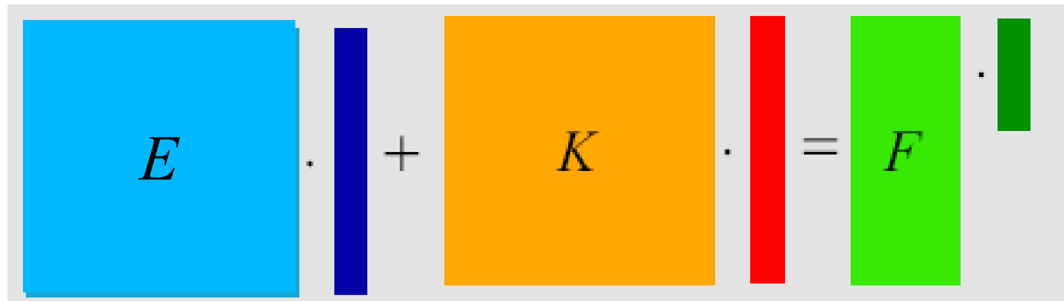


CADFEM

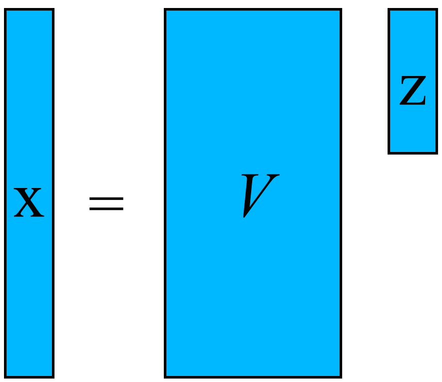
Model Reduction as Projection

- Projection onto low-dimensional subspace

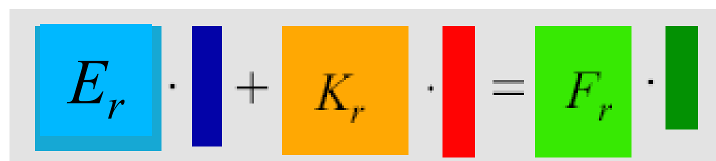
$$E\dot{\mathbf{x}} + K\mathbf{x} = B\mathbf{u}$$



$$\mathbf{x} = V\mathbf{z} + \varepsilon$$



$$V^T E V \dot{\mathbf{z}} + V^T K V \mathbf{z} = V^T B \mathbf{u}$$

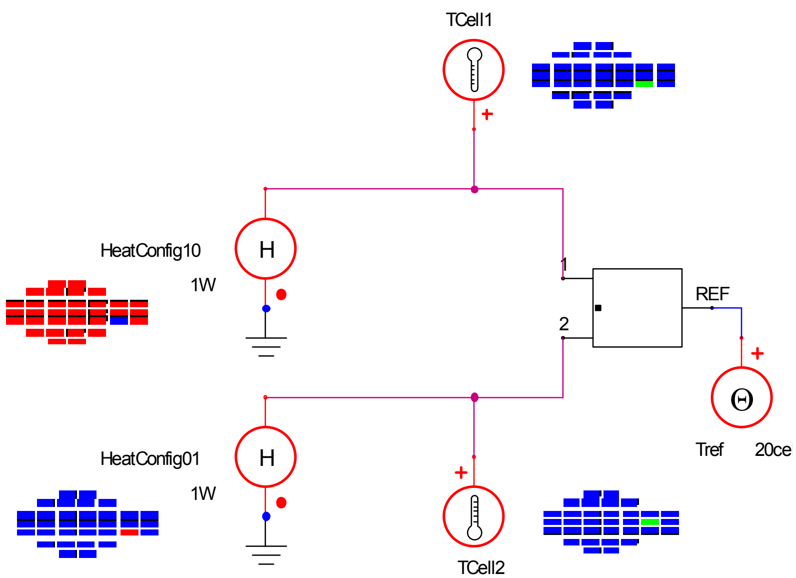


- How to find subspace?
- Mode superposition is not the best way to do it.

Battery case

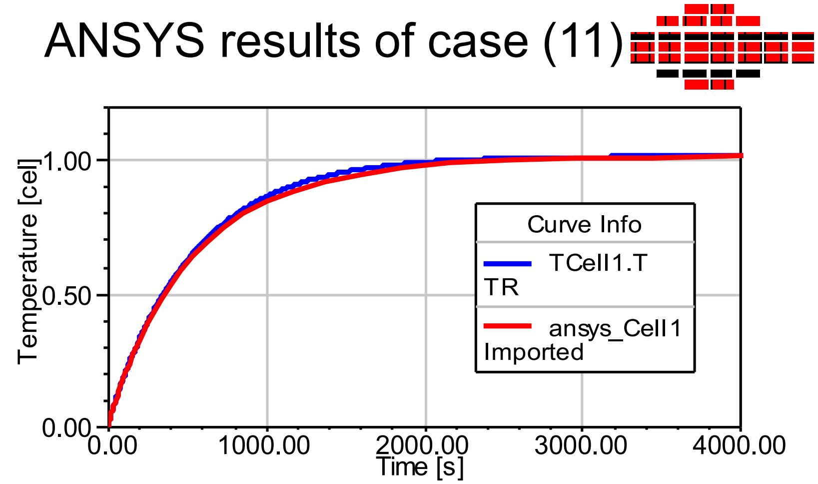
Circuit Thermal Model in Simplorer

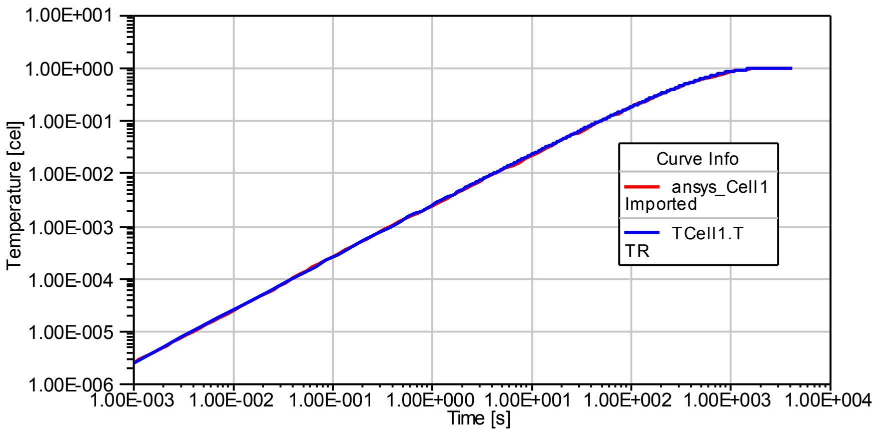
- State Space Battery thermal model
  - 2 Inputs of 1W/cell



Temperature reference: 0°C

ANSYS results of case (11)





CADFEM

Statistics

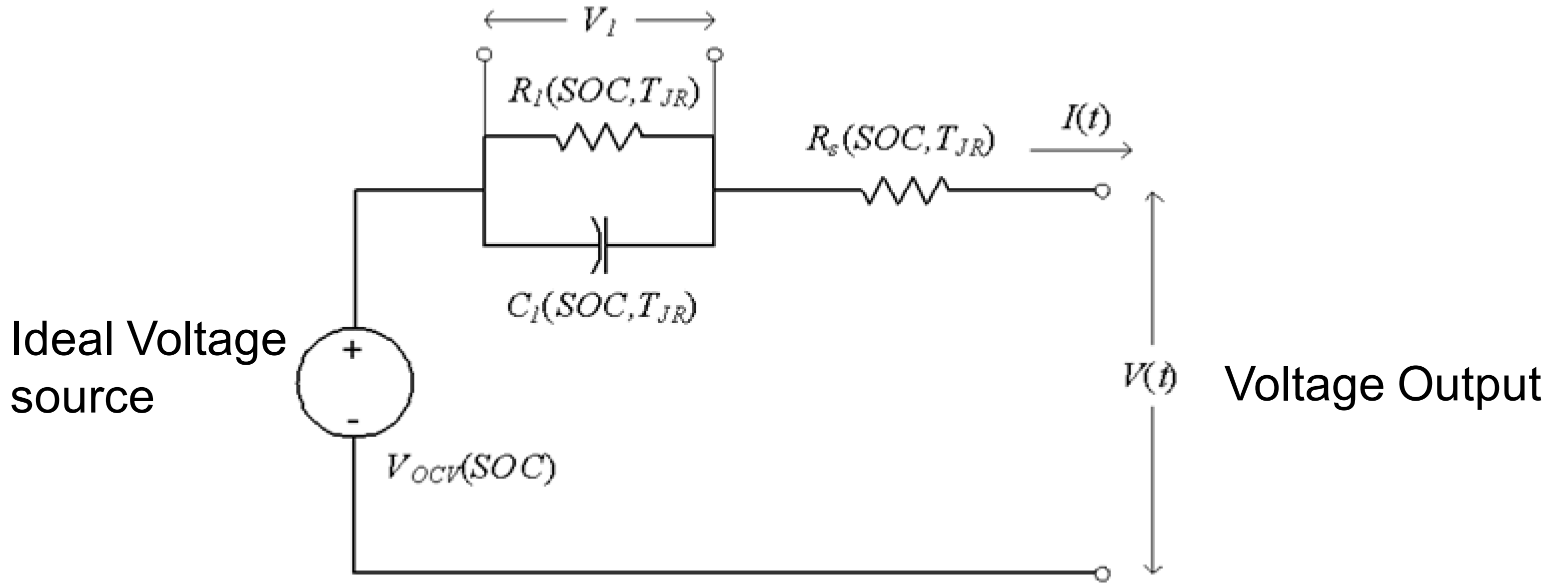
	System level	Device level (FEM)
Simulation time [s]	4000	4000 (100 timesteps)
Dimension	30 (15 x Input)	48500 elements
CPU time [s]	<1	2317 (~40min)

- System Level Thermal Simulation
  - Accurate results comparing to FE
  - **A thermal model at system level is now readily available to couple with electrical system**

CADFEM

Electrical Circuit for Li-ion Battery: 1 Cell

- **Equivalent** electrical circuit to model **electro-chemical effects** inside the cell



$$\frac{d}{dt}SOC = \frac{I}{Q}$$

$$\frac{d}{dt}V_I = \frac{-V_I}{R_I C_I} - \frac{I}{C_I}$$

$$V = V_{OCV} + V_I - R_s I$$

Resistance and Capacitance is a function of temperature and State of Charge (SOC)

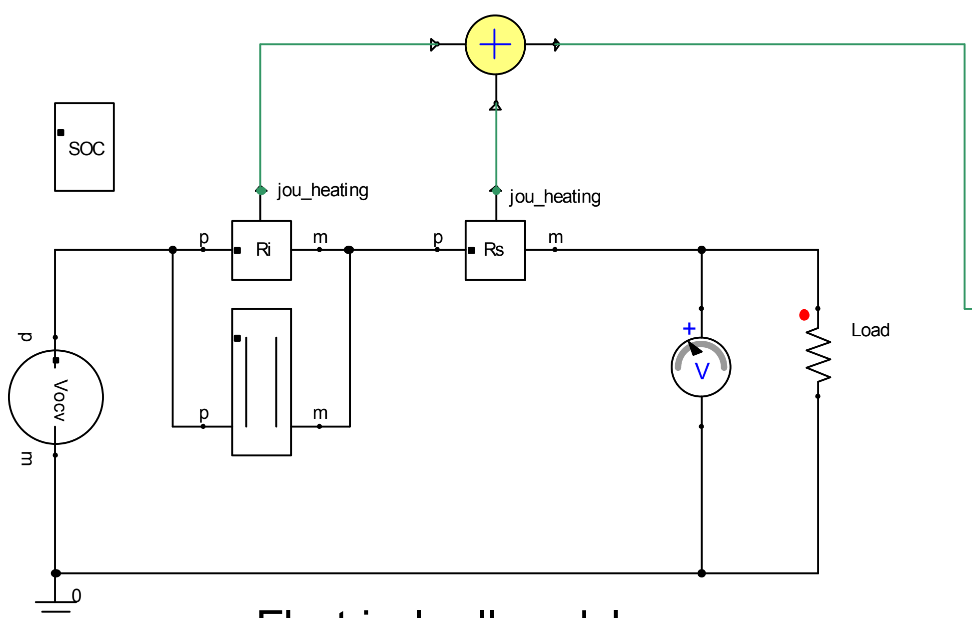
$$V_{OCV} = f(SOC)$$
$$R_I = f(SOC, T_{JR})$$
$$R_s = f(SOC, T_{JR})$$

experiments or sophisticated models

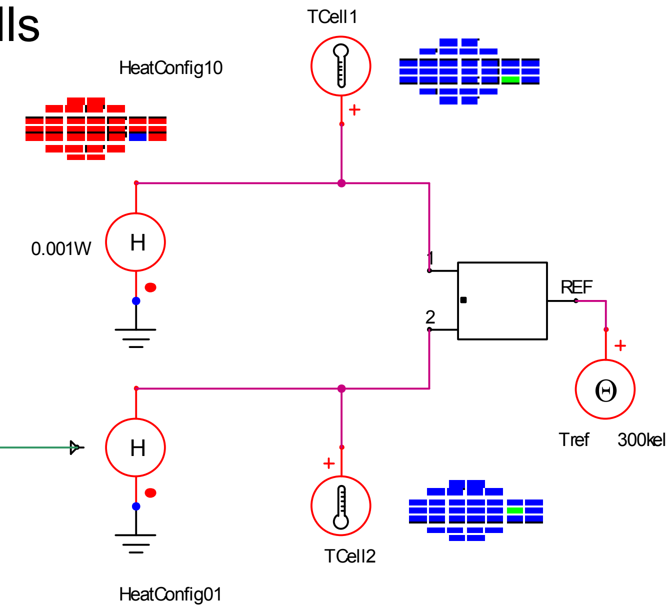
CADFEM

Electrical – Thermal Battery model

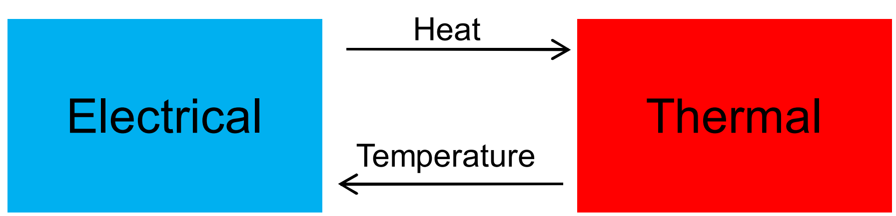
- Impedance electrical model
  - Just one cell, but easy extended to all 33 cells



Electrical cell model (cell1)

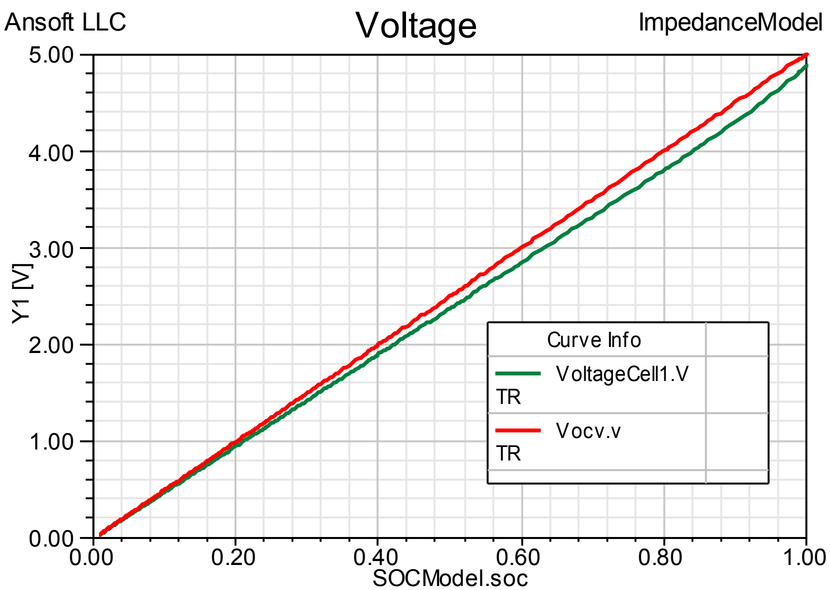


Battery thermal model

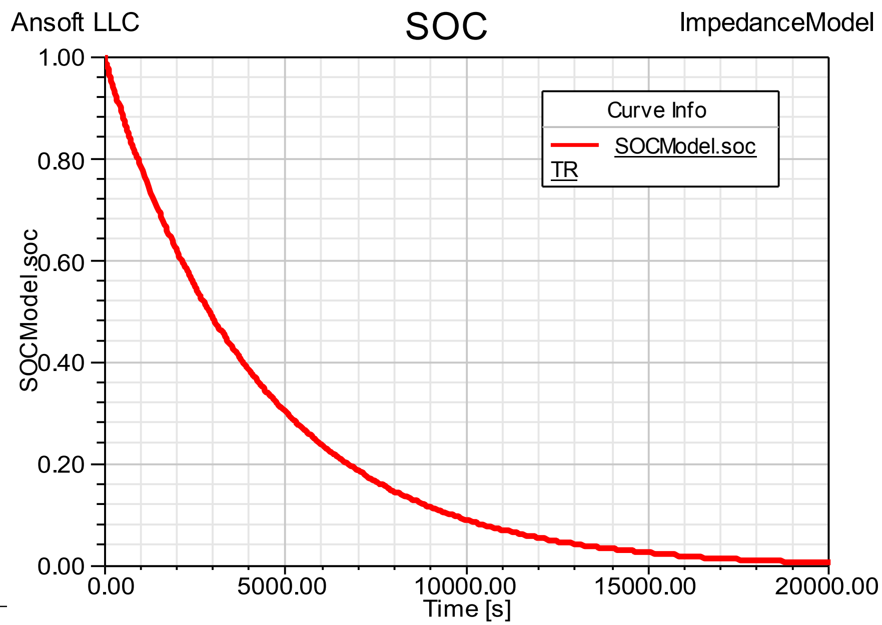


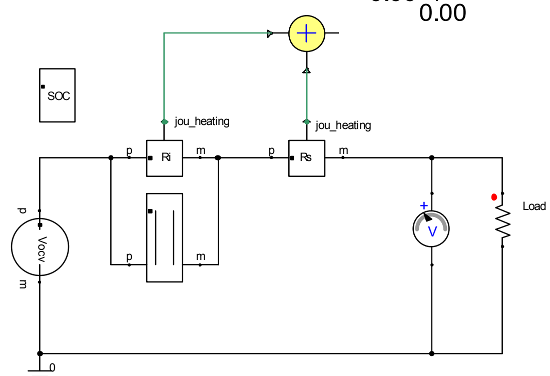
Results – Electrical behavior

- Minimum Voltage reached
  - End of discharging process



- Discharging process represented by SOC



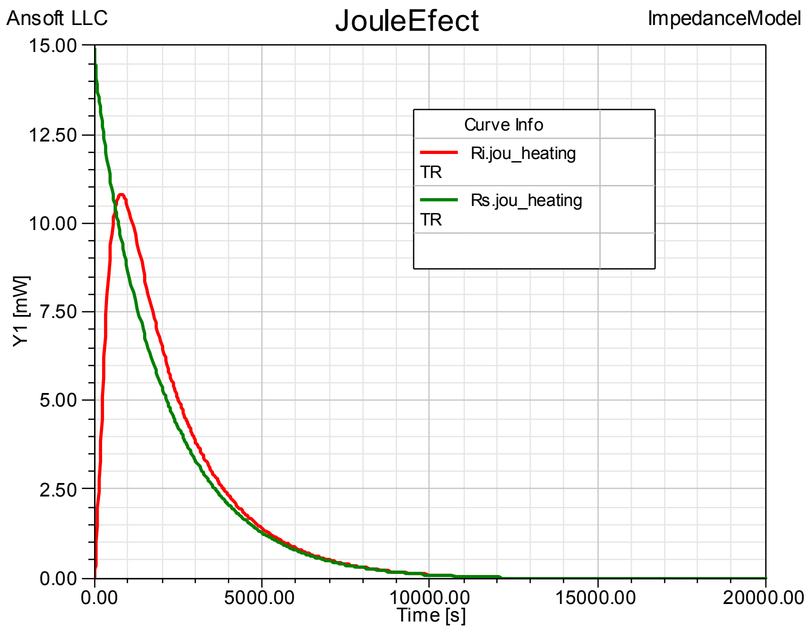


Electrical cell model (cell1)

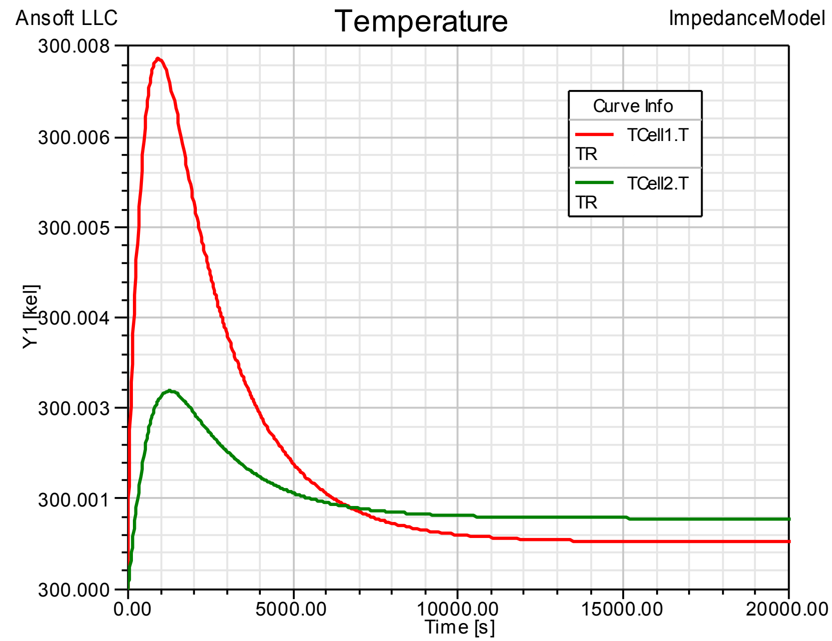
CADFEM

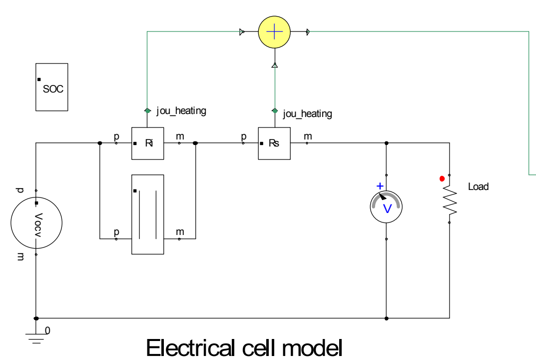
Results – Thermal behavior

- Joule effect due to resistors
  - $P=i^2R$

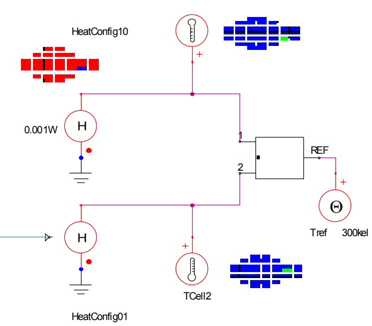


- Cell temperature rise





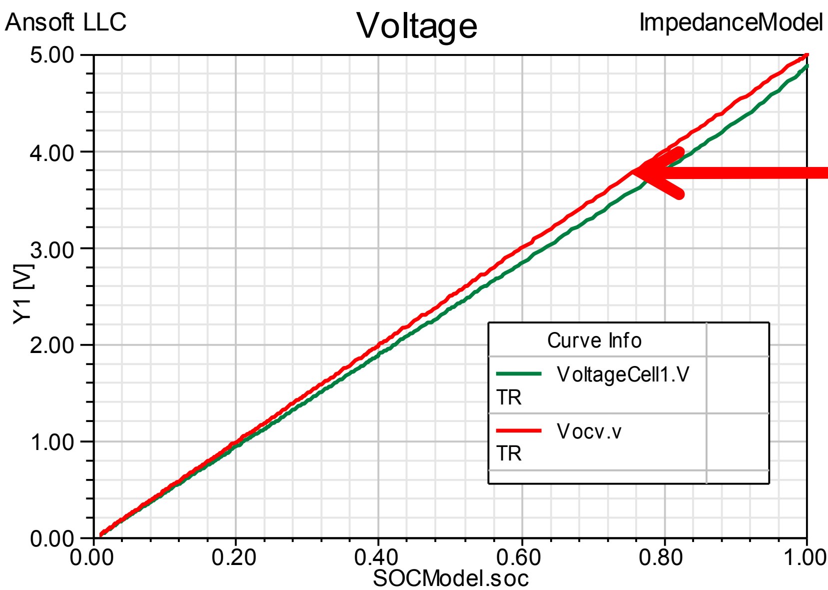
Electrical cell model
(cell1)

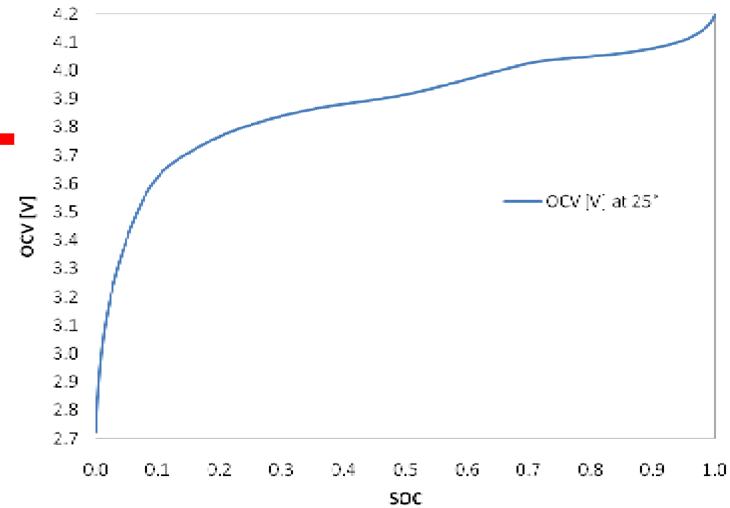


Battery thermal model

Experimental Data – Next step

- Battery characterization by LIONSmart





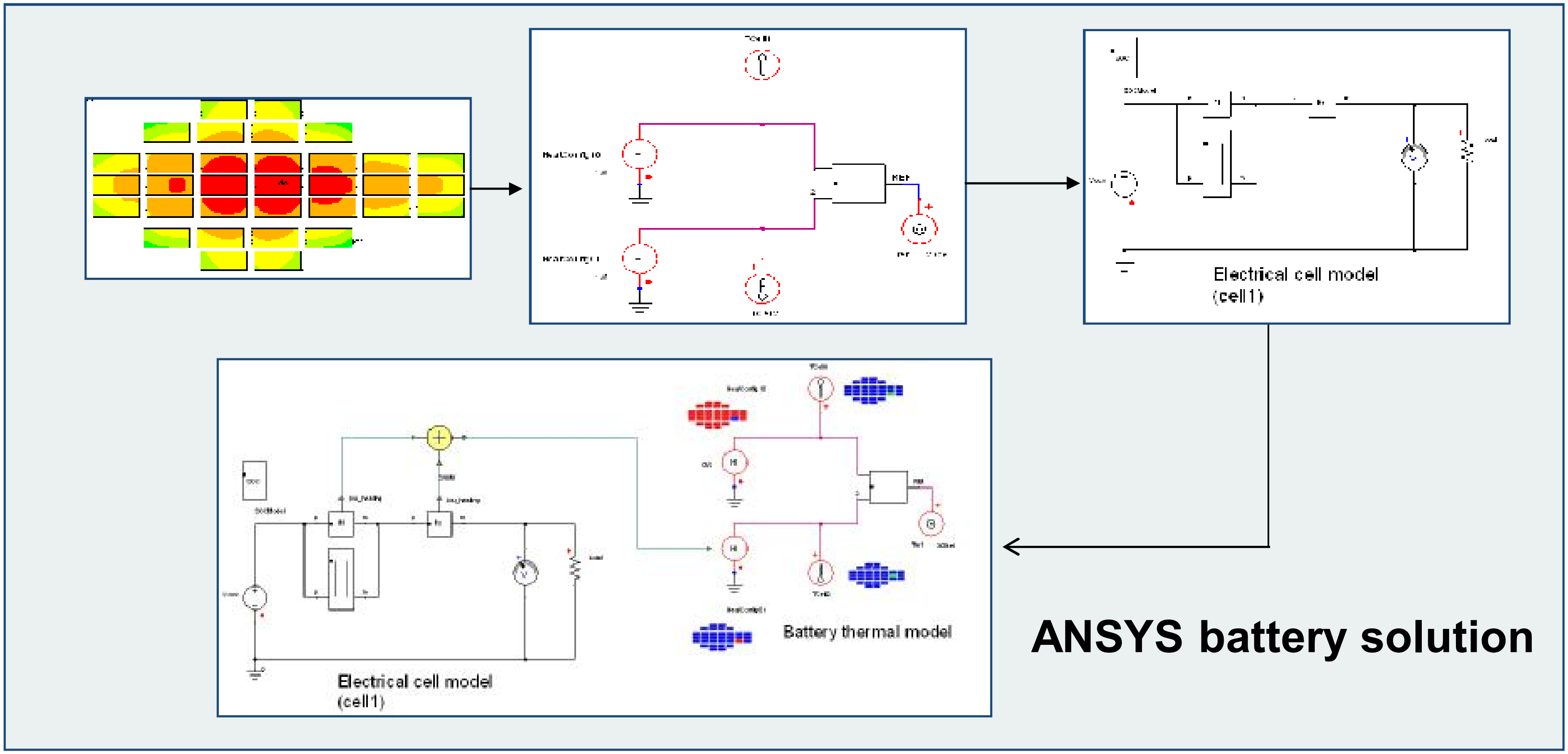
$$V_{OCV} = f(SOC)$$
$$R_I = f(SOC, T_{JR})$$
$$R_s = f(SOC, T_{JR})$$

Experimental characterization

CADFEM

Conclusion

ANSYS provides solution platform to simulate the complete battery system including bi-directional thermal-electrical coupling



CADFEM