

$$\bar{\Pi} = \frac{1}{2} \sum_c \{u\}^T \cdot [K] \cdot \{u\} - \{u\} \cdot \{r\}$$

FEM SOFTWARE AND SERVICES



System Level Battery Thermal Behavior Study

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ANSYS[®]

ANSYS Competence Center FEM

CADFEM[®]

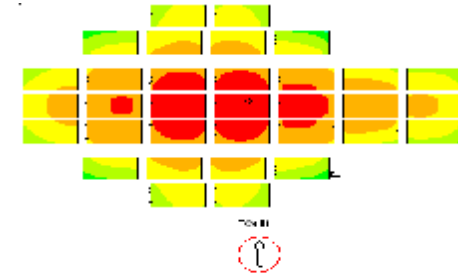
Scope and Objective

- Battery temperature under control means:
 - Optimal capacity
 - Optimal life
 - Safety operation
- Thermal phenomena coupled with electro-chemical
 - Heat generation: Chemical Reaction and Joule Effect
 - Heat transfer: Cooling by convection and conduction
- **The goal is:**
 - **To control the temperature in the battery pack**
 - Battery ageing
 - Safety reason (explosion)

Approach

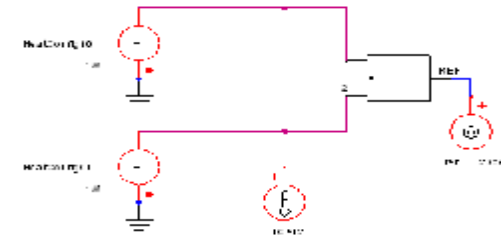
▪ Device level thermal simulation

- ANSYS Thermal Model
- Simulation of transient behavior of battery



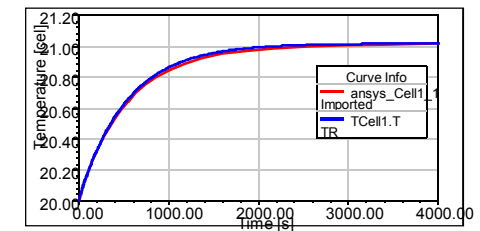
▪ System level thermal simulation

- Simplorer Circuit Model
- Thermal circuit model (reduced model) generated by MOR for ANSYS



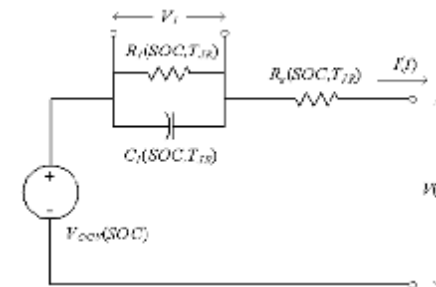
▪ Verification

- Compare results of reduced model with FEM model

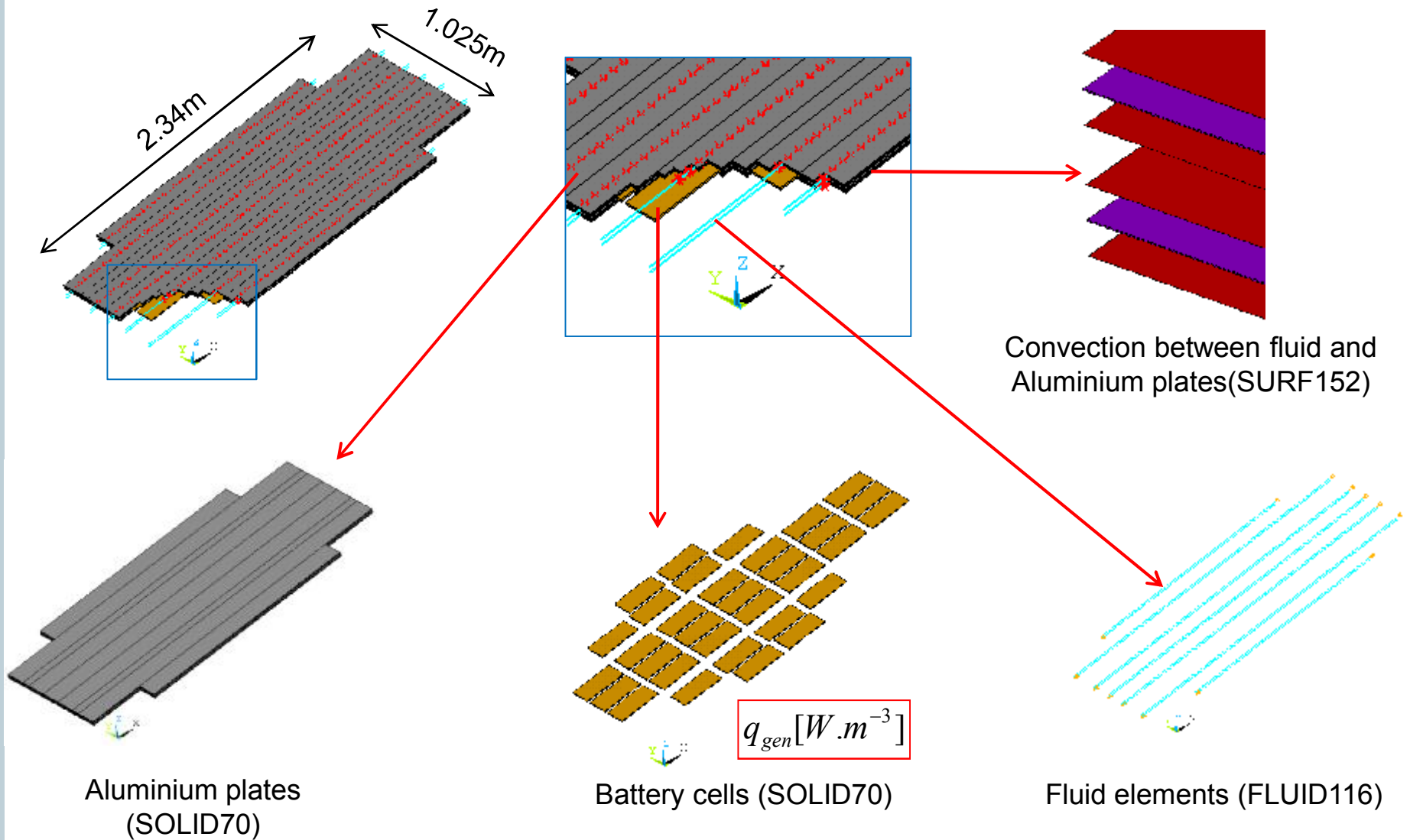


▪ System level Electric-Thermal simulation

- Include electric behavior model

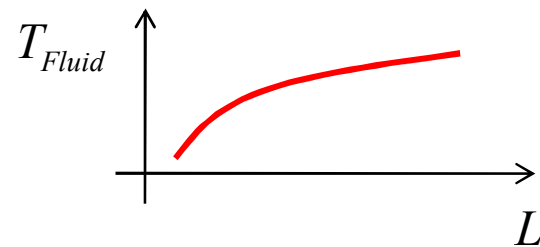


ANSYS Battery Model



Simplified CFD model - Air Cooling

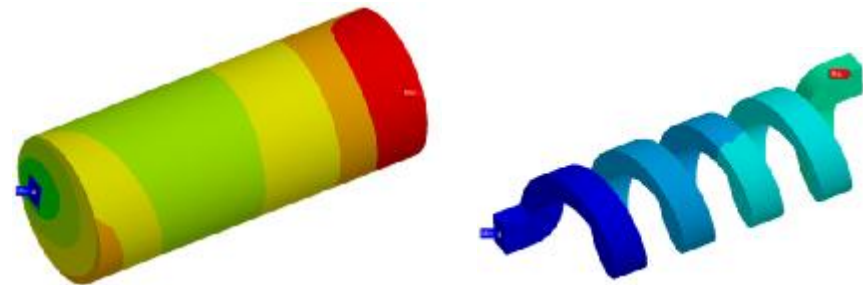
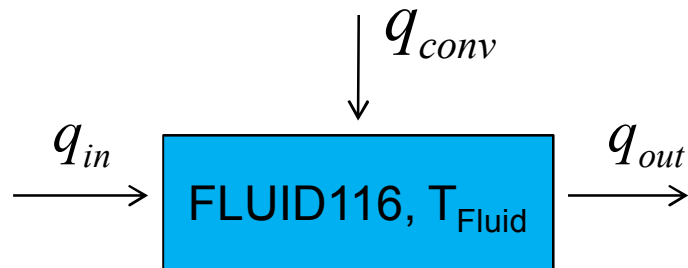
- Compute temperature rise of cooling air



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

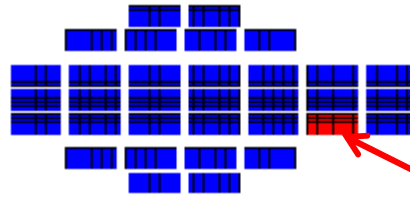
$$q_{conv} = h(T - T_{Fluid})$$

(SURF152)



Case of Study

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



Extra heat generation

- 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 ?



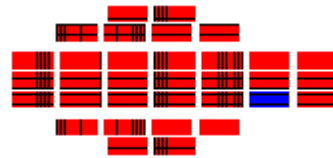
“Detailed”
information with fast
response is needed

Configuration – ANSYS and MOR

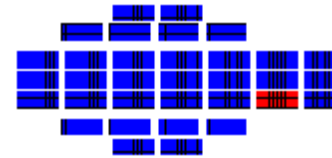
- Two Independent INPUTs

- Heat generation
 - 1W /Cell

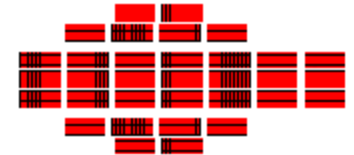
10



01

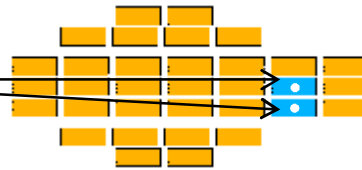


11



- OUTPUT

- Temperature



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

3 ANSYS models

11

01

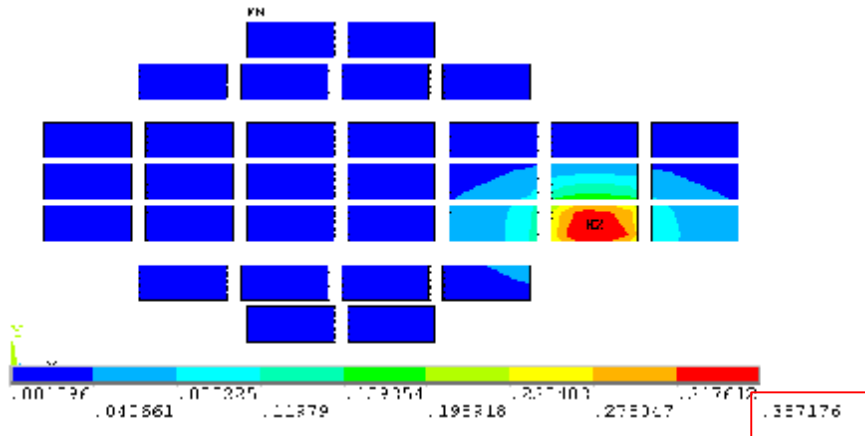
10

MOR for
ANSYS

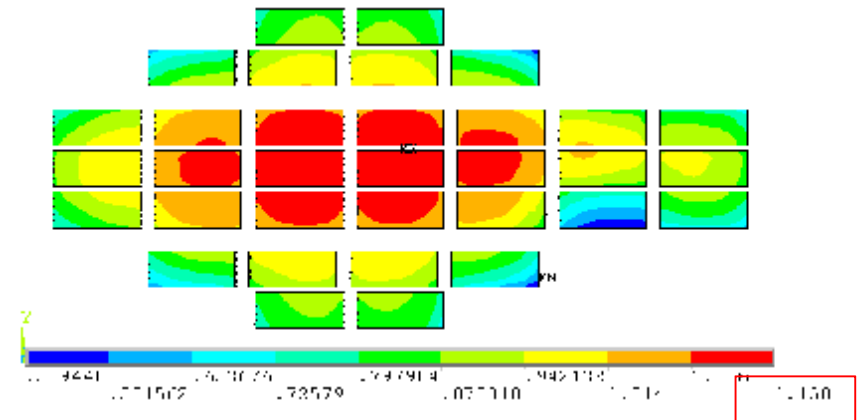
Reduced order
model

Independent of Input functions
Simulation not needed, just matrices

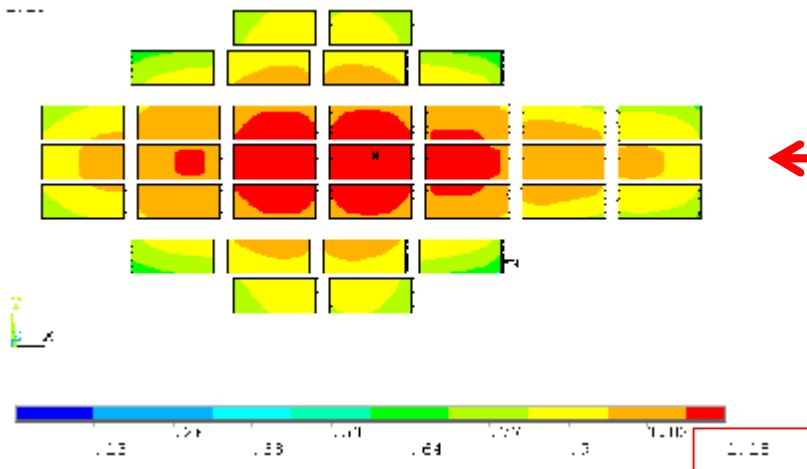
ANSYS Transient Thermal Battery Model



Load case 01 @ 4000 seconds



Load case 10 @ 4000 seconds



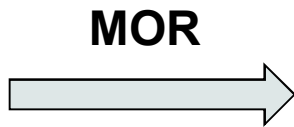
Load case 11 @ 4000 seconds



Selected for comparison with reduced order model

From ANSYS to Simplorer through MOR

ANSYS matrices

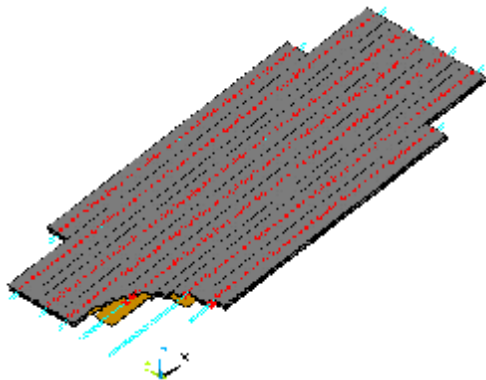


Reduced Model

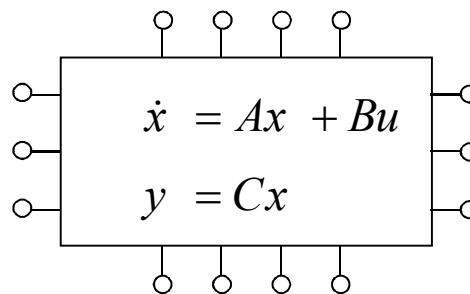


Simplorer

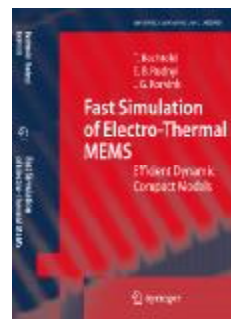
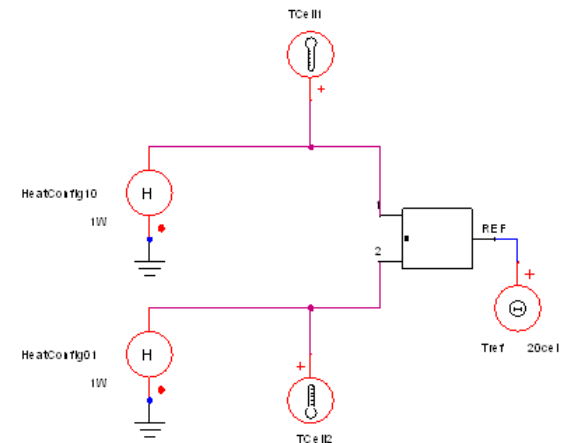
Complete FEM model



Reduced dimension (State Space Model)

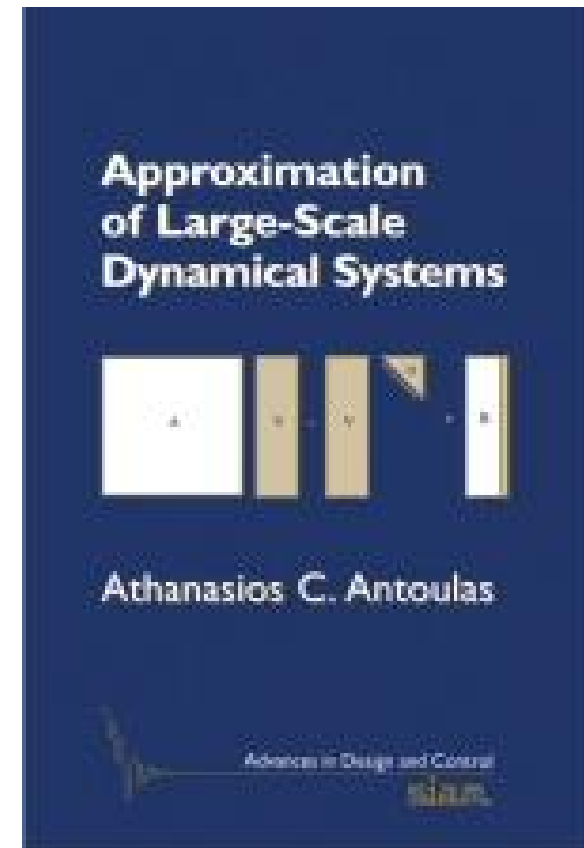


System level simulation



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



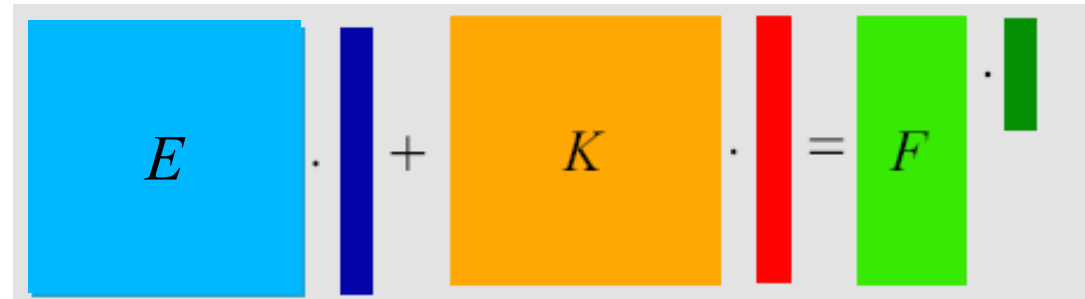
Model Reduction as Projection

- Projection onto low-dimensional subspace

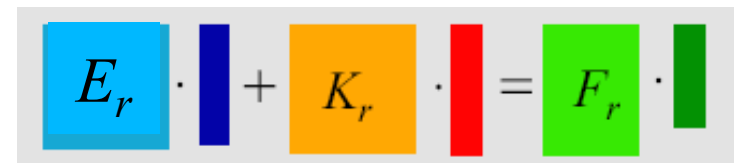
$$\mathbf{x} = V\mathbf{z} + \varepsilon$$

A diagram illustrating the projection of a vector \mathbf{x} onto a subspace V to obtain a vector \mathbf{z} . The vector \mathbf{x} is represented by a tall blue rectangle on the left. The matrix V is a larger blue rectangle in the center. The vector \mathbf{z} is a shorter blue rectangle on the right. The equation $\mathbf{x} = V\mathbf{z} + \varepsilon$ is written above the diagram.

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



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

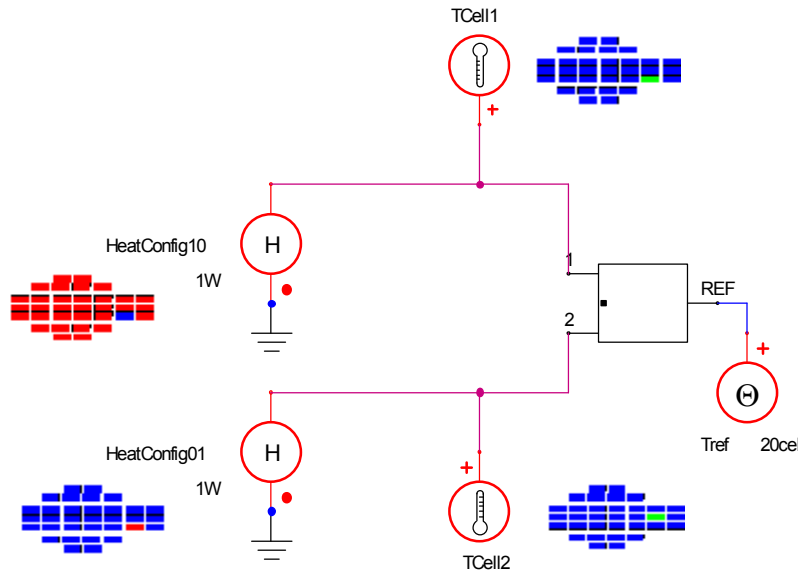


- How to find subspace?
- Mode superposition is not the best way to do it.

Battery case

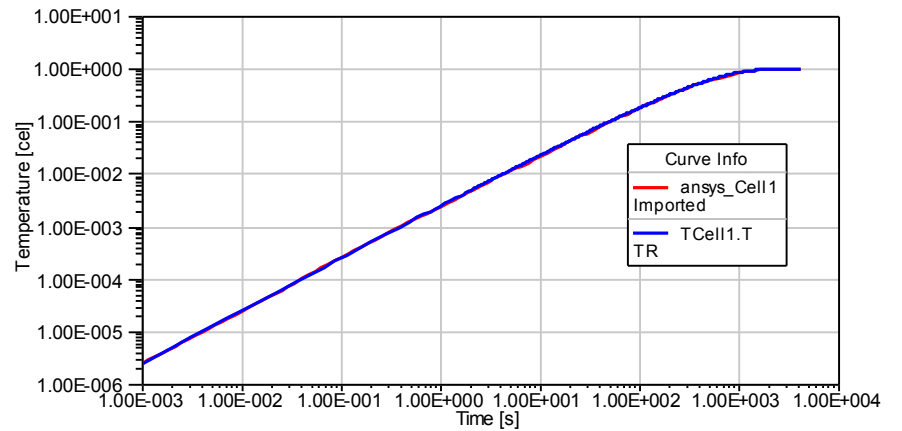
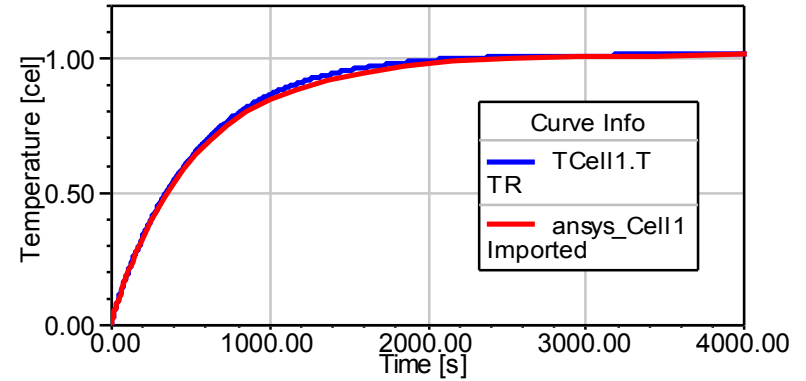
Circuit Thermal Model in Simplorer

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



Temperature reference: 0°C

ANSYS results of case (11)



Statistics

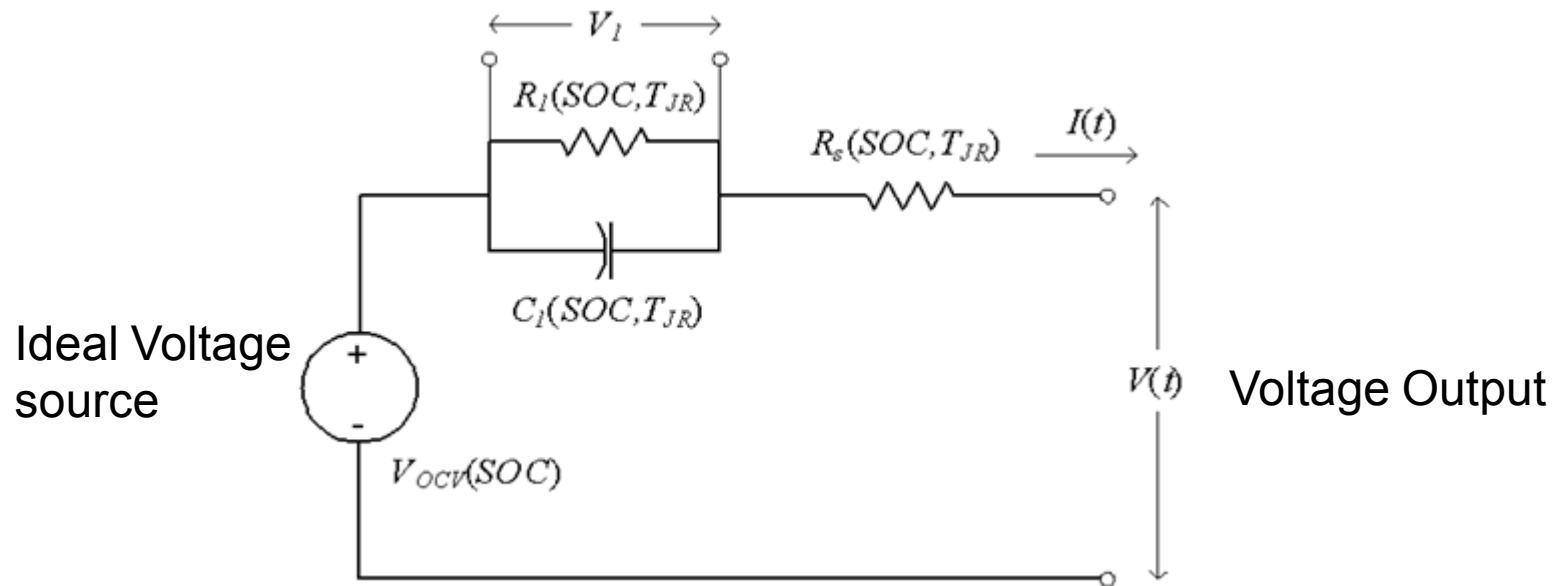
	System level	Device level (FEM)
Simulation time [s]	4000	4000 (100 timesteps)
Dimension	30 (15 x Input)	48500 elements
CPU time [s]	<1	2317 (~40min)

■ System Level Thermal Simulation

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

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)

$$V_{OCV} = f(SOC)$$

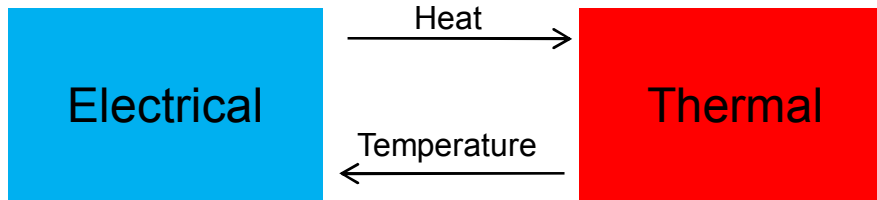
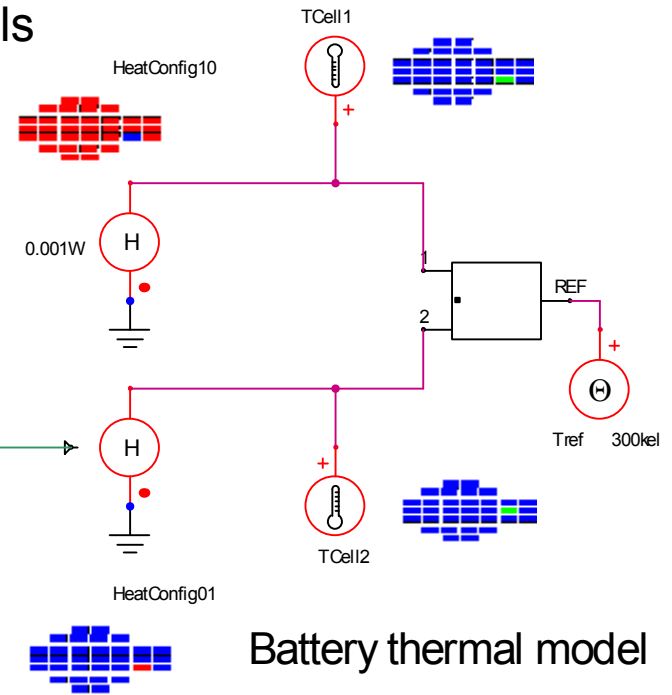
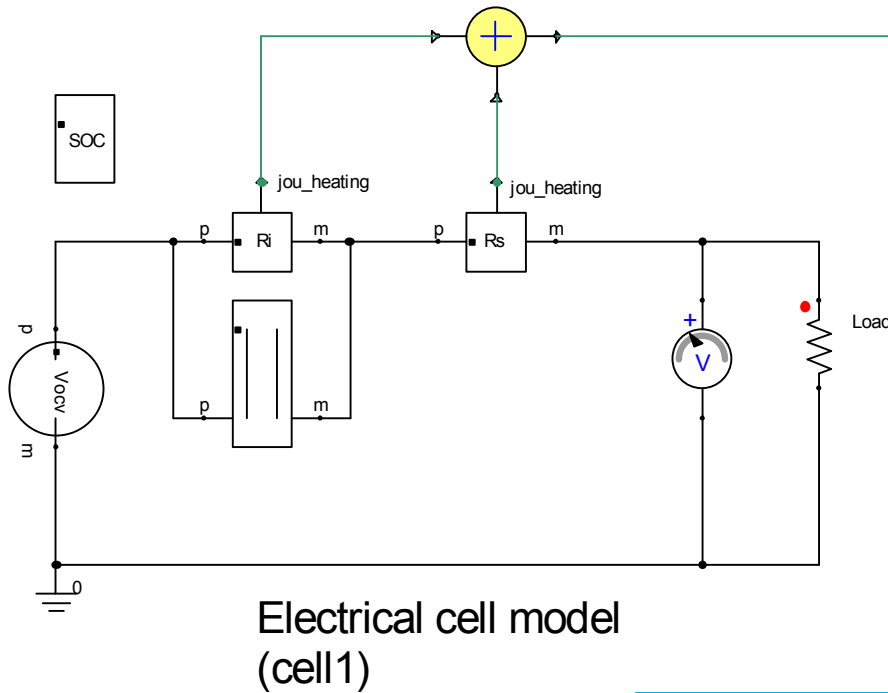
$$R_I = f(SOC, T_{JR})$$

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

experiments or sophisticated models

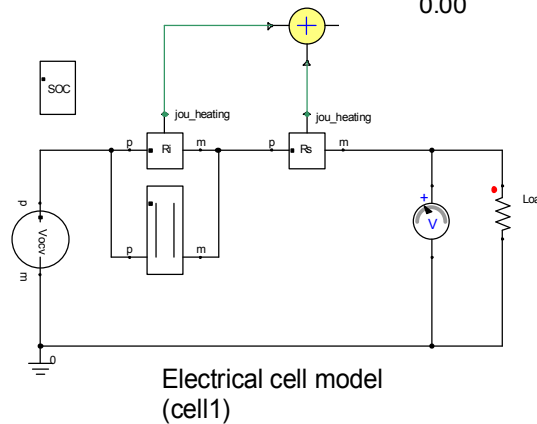
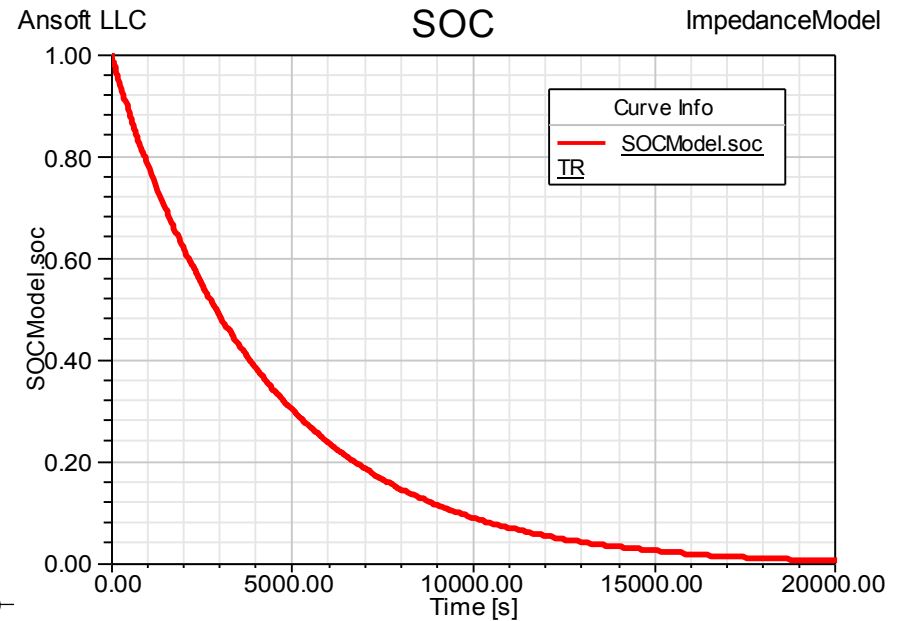
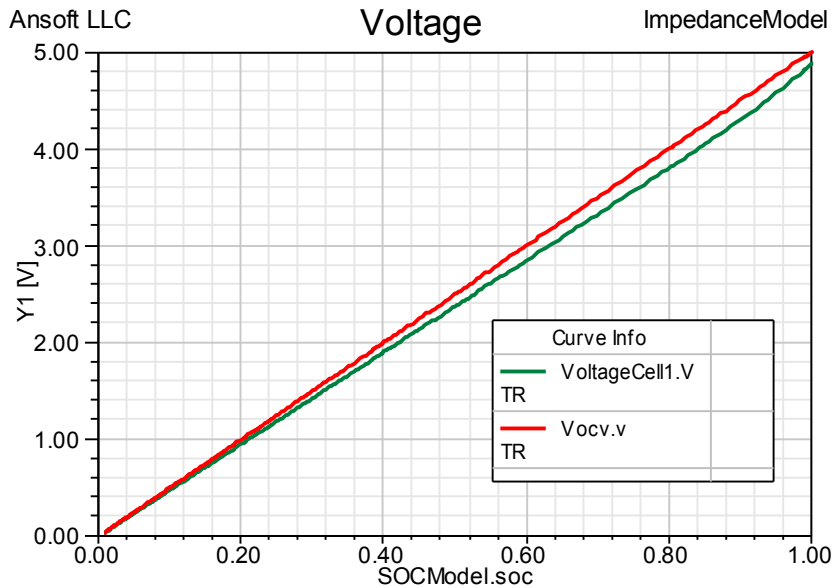
Electrical – Thermal Battery model

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



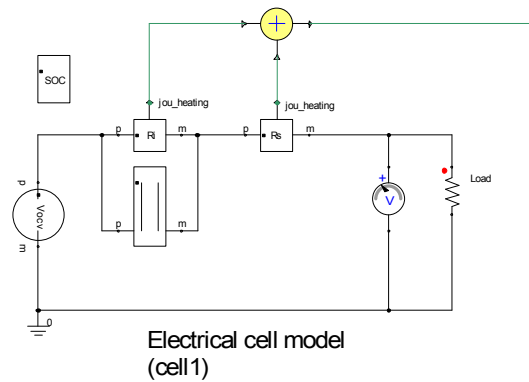
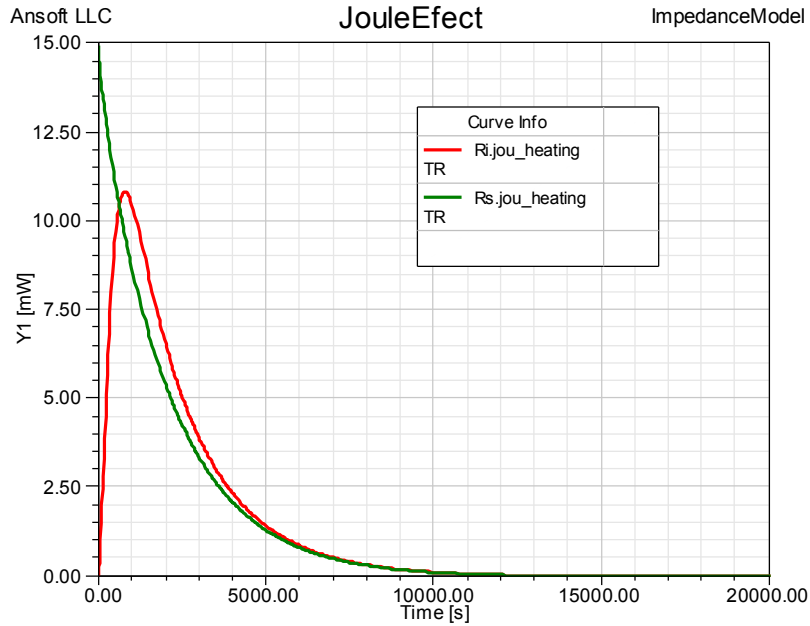
Results – Electrical behavior

- Minimum Voltage reached
 - End of discharging process
- Discharging process represented by SOC

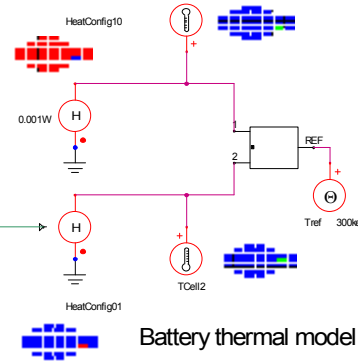
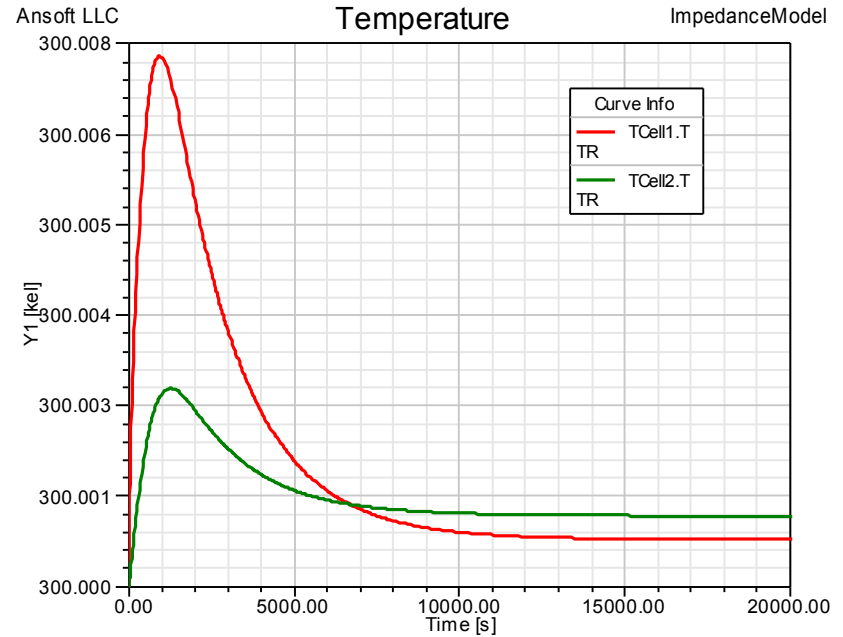


Results – Thermal behavior

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

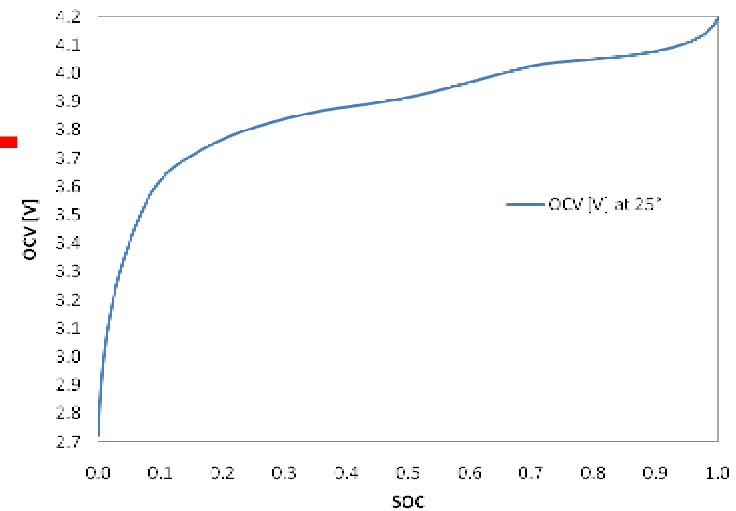
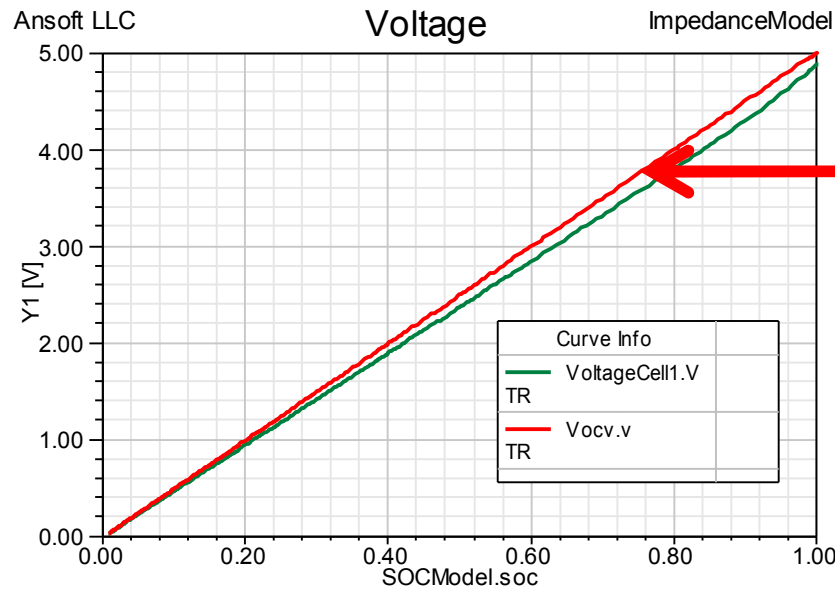


- Cell temperature rise



Experimental Data – Next step

- Battery characterization by



$$\left. \begin{aligned} V_{OCV} &= f(SOC) \\ R_I &= f(SOC, T_{JR}) \\ R_s &= f(SOC, T_{JR}) \end{aligned} \right\}$$

Experimental characterization

Conclusion

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

