Busbar Sizing Modeling Tools: Comparing an ANSYS® based 3D Model with the Versatile 1D Model Part of MHD-Valdis

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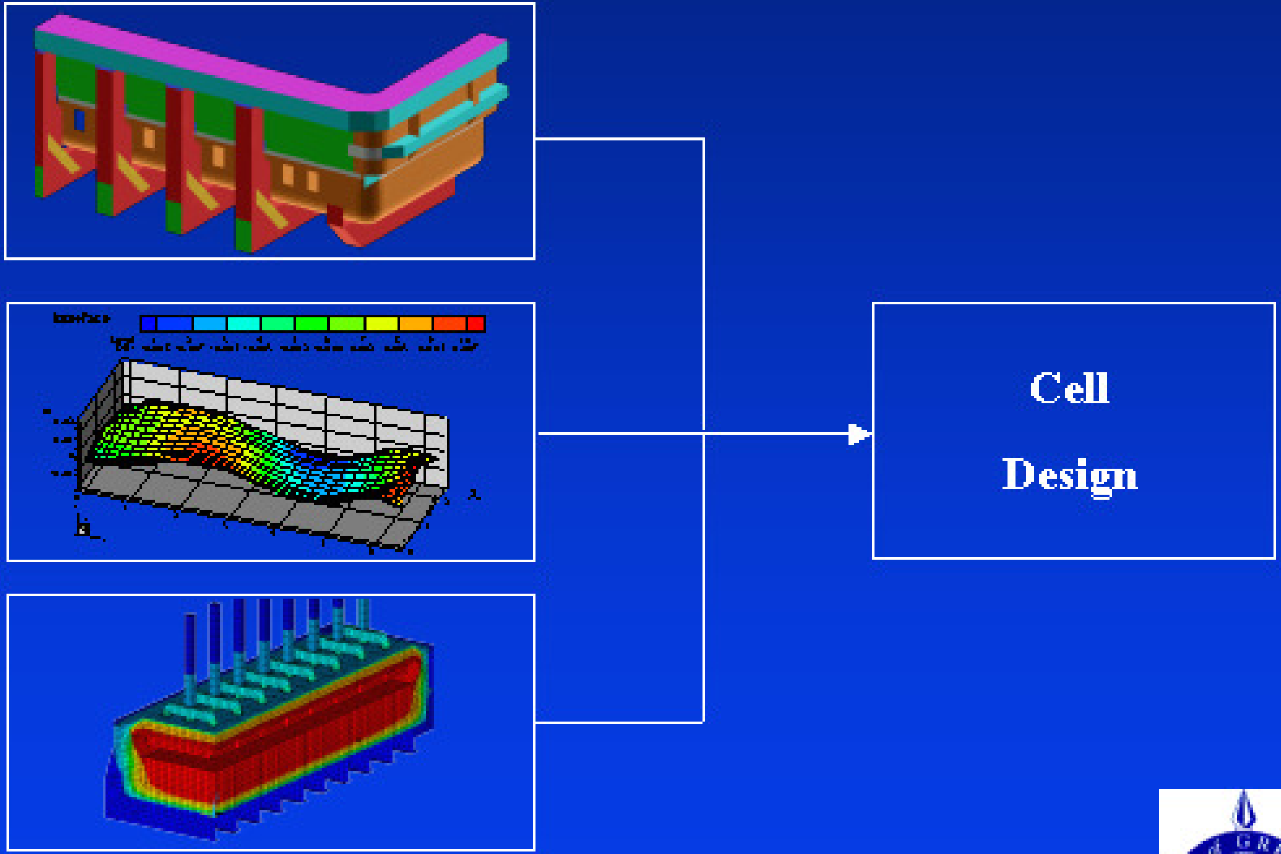
Plan of the Presentation

- Introduction
- 1D Busbar Heat Balance and Voltage Drop Equations
- 3D ANSYS® based busbar model
- 1D ANSYS® based busbar model
  - First version
  - Second version
- Versatile 1D busbar model part of MHD-Valdis
- Conclusions

Modeling the Hall-Héroult Cell

Currently, we can fit Hall-Héroult mathematical models into three broad categories:

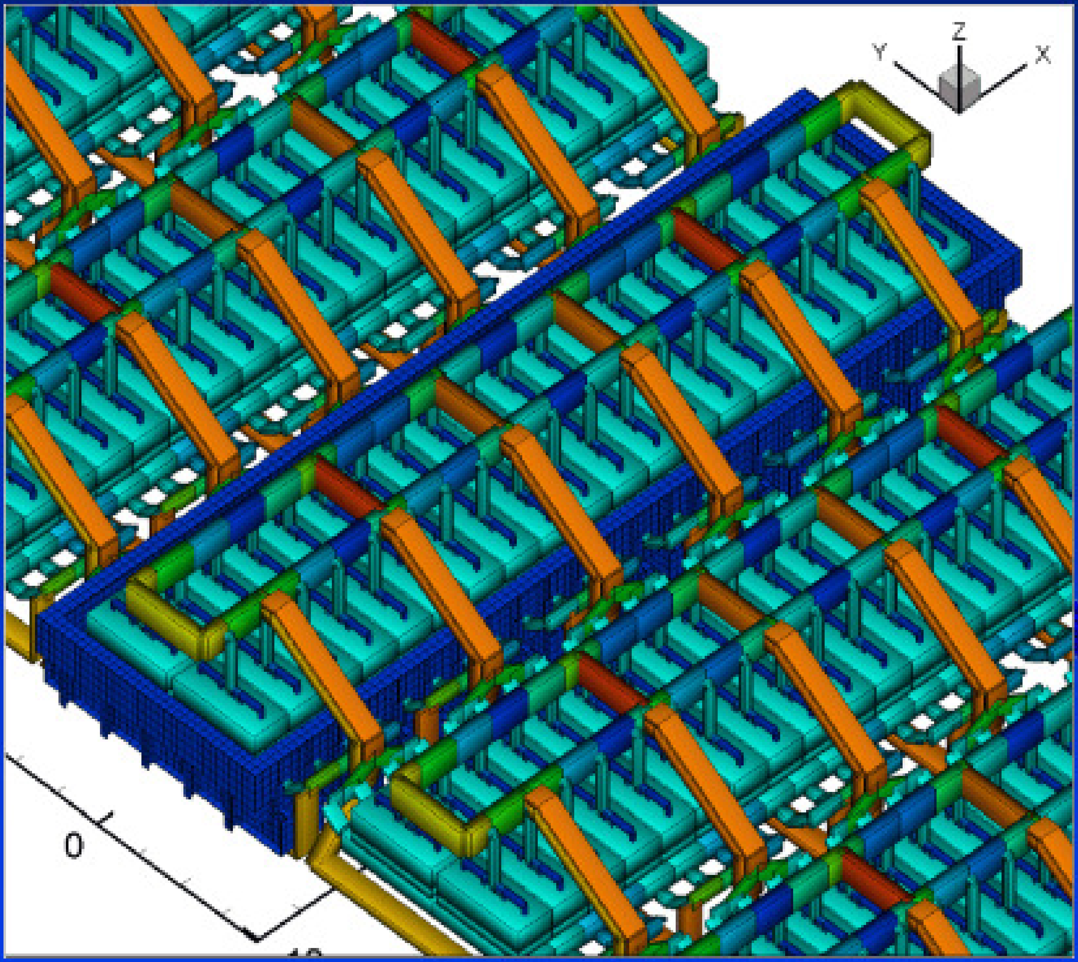
- Stress models which are generally associated with cell shell deformation and cathode heaving issues.
- Magneto-hydro-dynamic (MHD) models which are generally associated with the problem of cell stability.
- Thermal-electric models which are generally associated with the problem of cell heat balance.

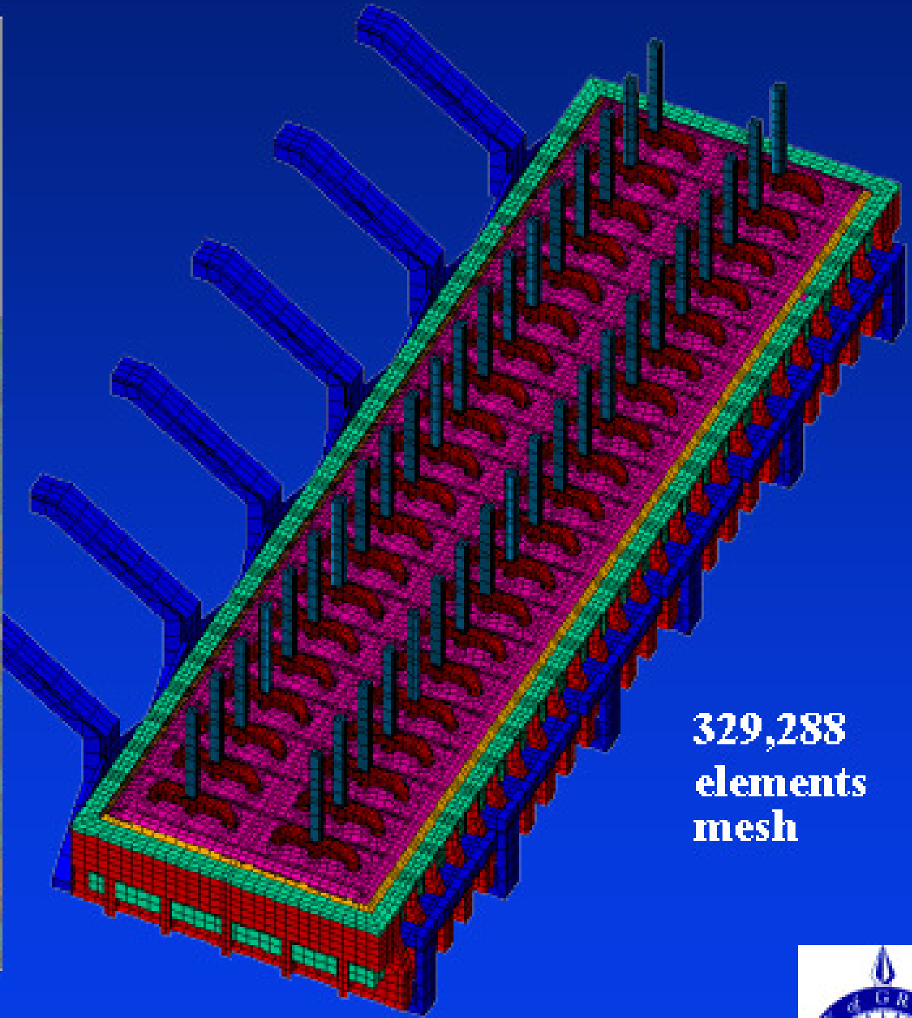


Cell

Design

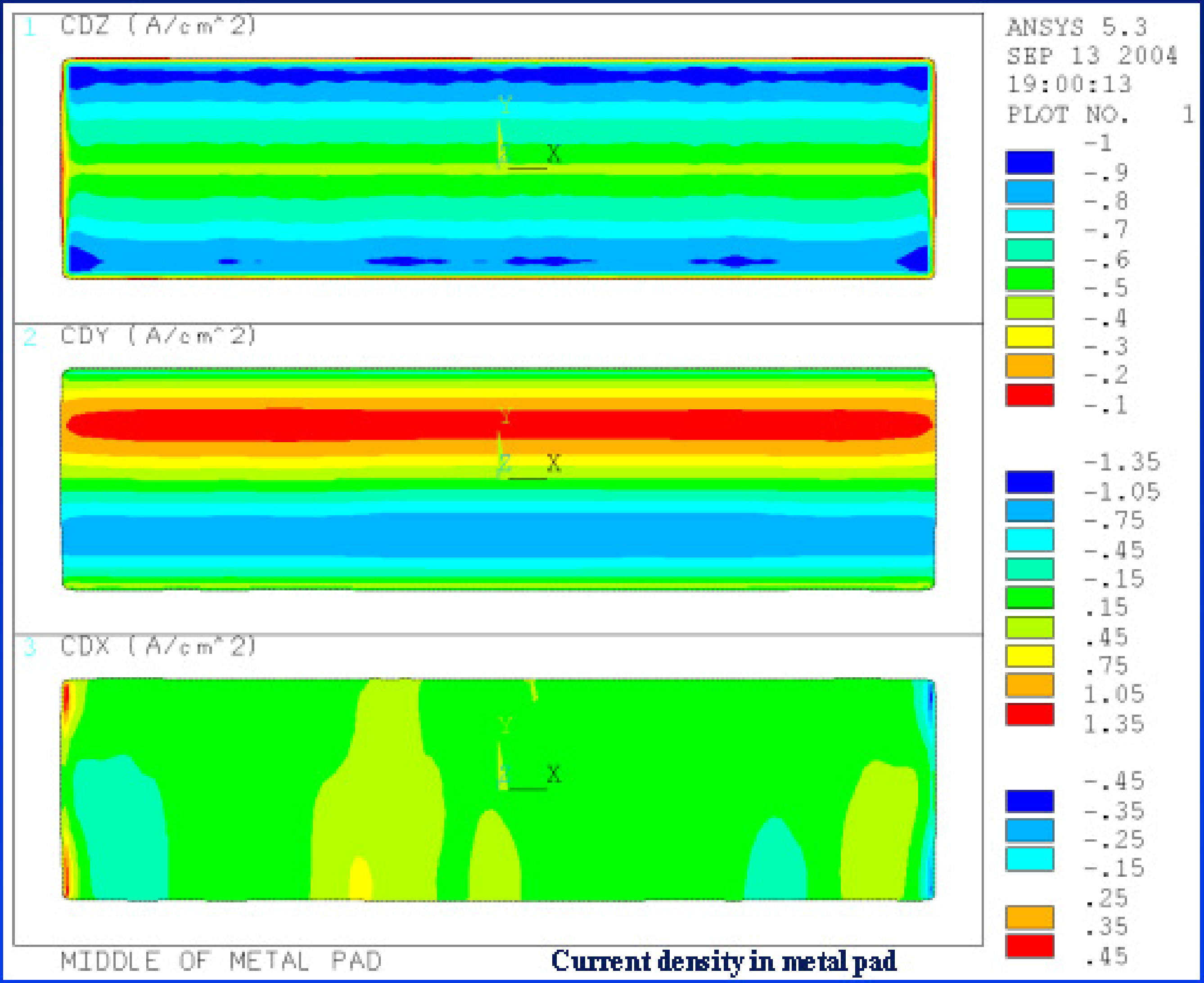
1D vs. 3D Thermo-Electric Models



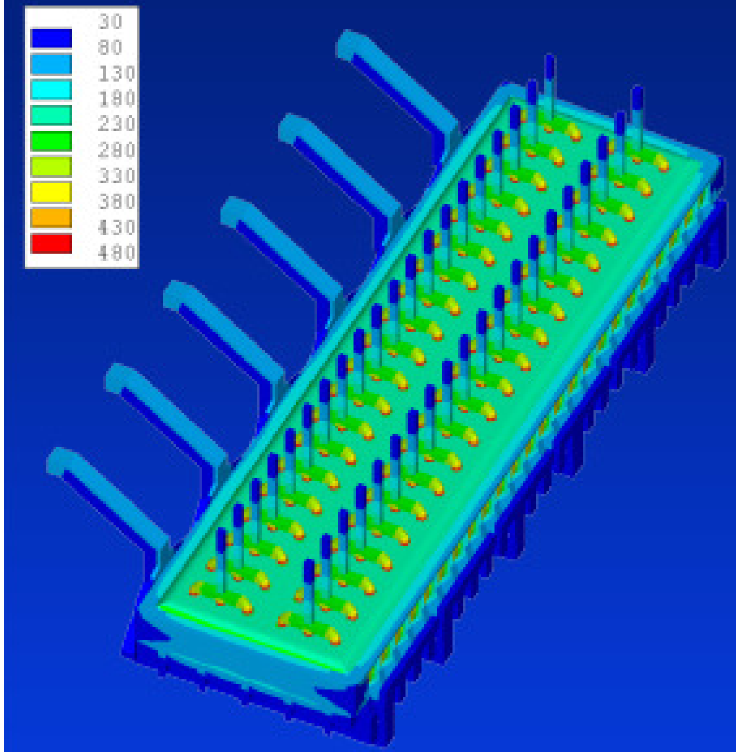


329,288
elements
mesh

Full 3D Thermo-Electric Model Results



Current density in metal pad



A P4 computer took "only" 40.6 CPU hours to solve the model 6 times

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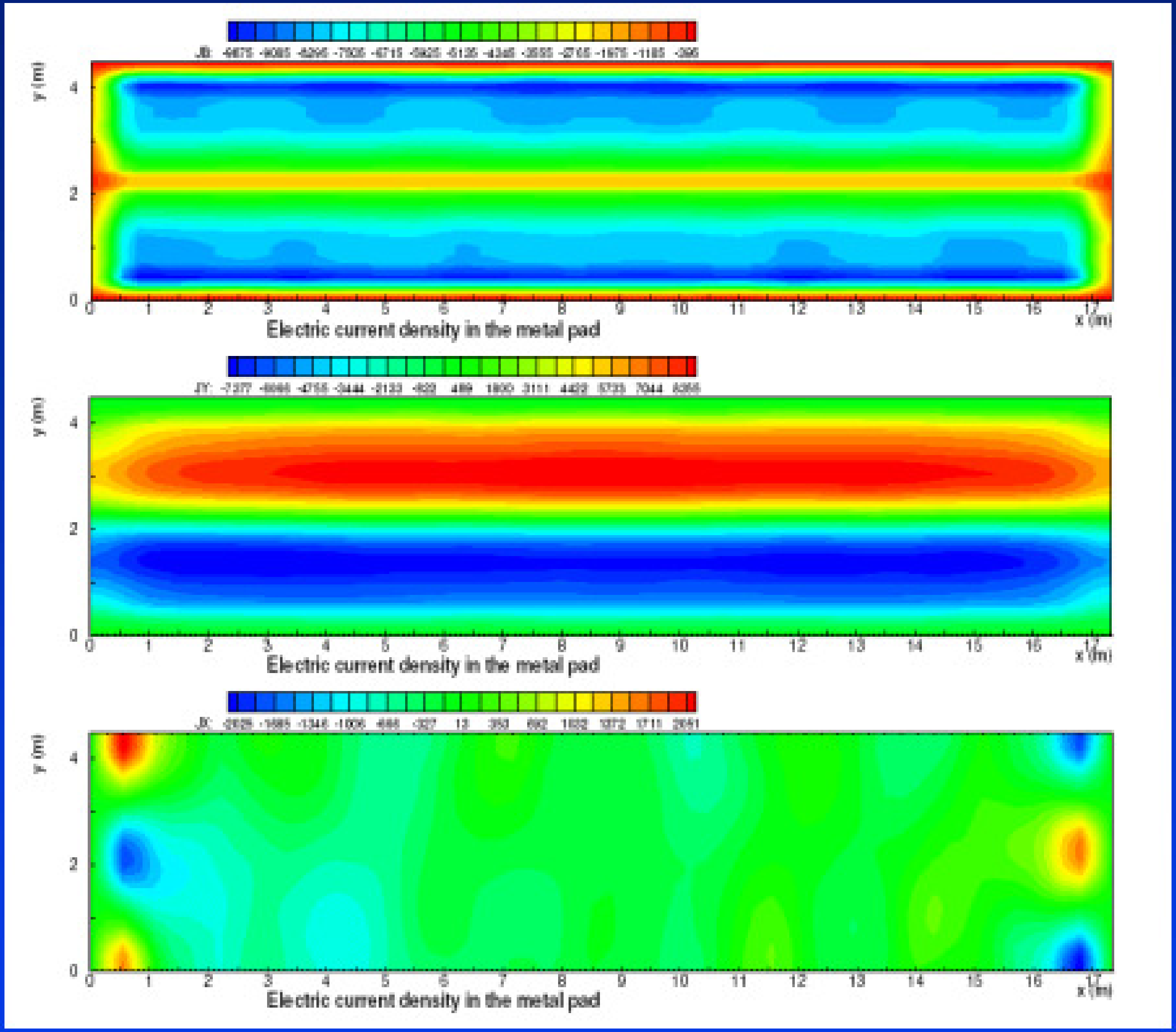
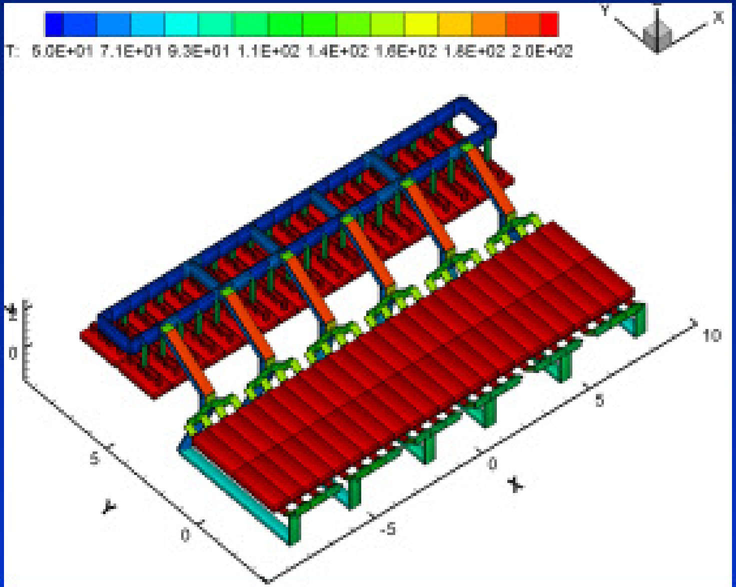
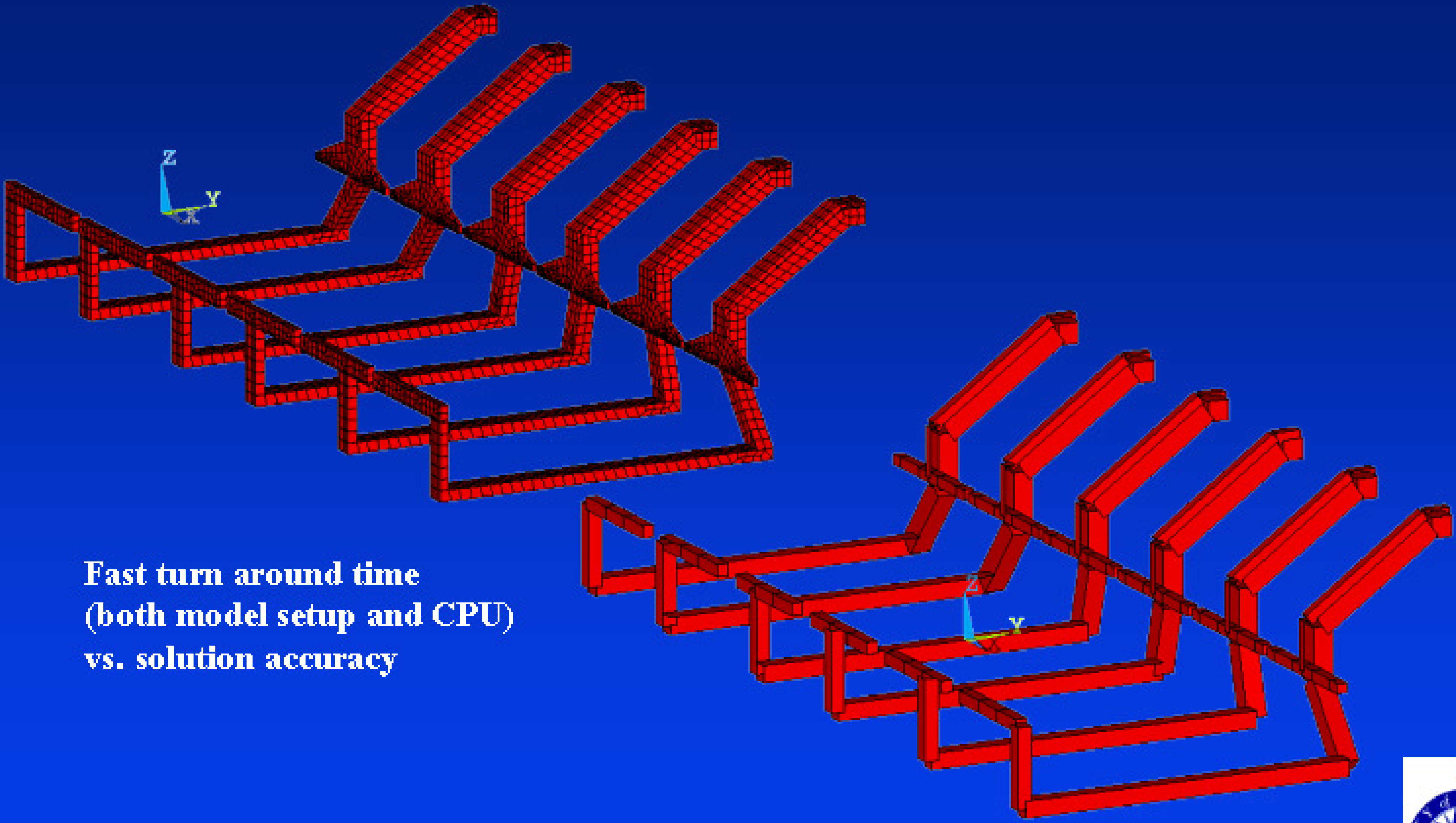
1D Thermo-Electric Model Results





Solution computed in no more than a few seconds

Busbar Sizing Modeling Tools: 1D vs. 3D



Fast turn around time
(both model setup and CPU)
vs. solution accuracy

1D Busbar Heat Balance and Voltage Drop Equations

$$A(m^2) = 2 \times (H + W) \times L$$

$$S(m^2) = H \times W$$

$$R(ohm) = \frac{\rho(T_B) \times L}{S}$$

$$\rho(ohm \cdot m) = \rho_0 \times (1 + \alpha_\rho \times T_B)$$

$$R \times I^2 (W) = \frac{k}{L} \times S \times (T_B - T_N) + h(T_B) \times A \times (T_B - T_{air})$$

$$R \times I \quad (V) = (V_B - V_N)$$

$$\sum I = 0$$

1D Busbar Heat Balance and Voltage Drop Equations

$$h(W/m^2\,°\mathrm{C}) = h_C(T_B) + h_R(T_B)$$

$$h_C(W/m^2\,°\mathrm{C}) = \frac{Nu \times k_{film}}{L}$$

$$h_R(W/m^2\,°\mathrm{C}) = \varepsilon\sigma(T_B + T_{air})(T_B^2 + T_{air}^2)$$

1D Busbar Heat Balance and Voltage Drop Equations

For vertical surfaces, we have:

$$Nu = 0.59\, Ra^{1/4}, \text{ for } 10^4 \le Ra \le 10^9$$

$$Nu = 0.105\, Ra^{1/3}, \text{ for } 10^9 \le Ra \le 10^{12}$$

For horizontal surfaces facing up we have:

$$Nu = 0.54\, Ra^{1/4}, \text{ for } 10^5 \le Ra \le 2 \times 10^7$$

$$Nu = 0.141\, Ra^{1/3}, \text{ for } 10^7 \le Ra \le 10^{11}$$

1D Busbar Heat Balance and Voltage Drop Equations

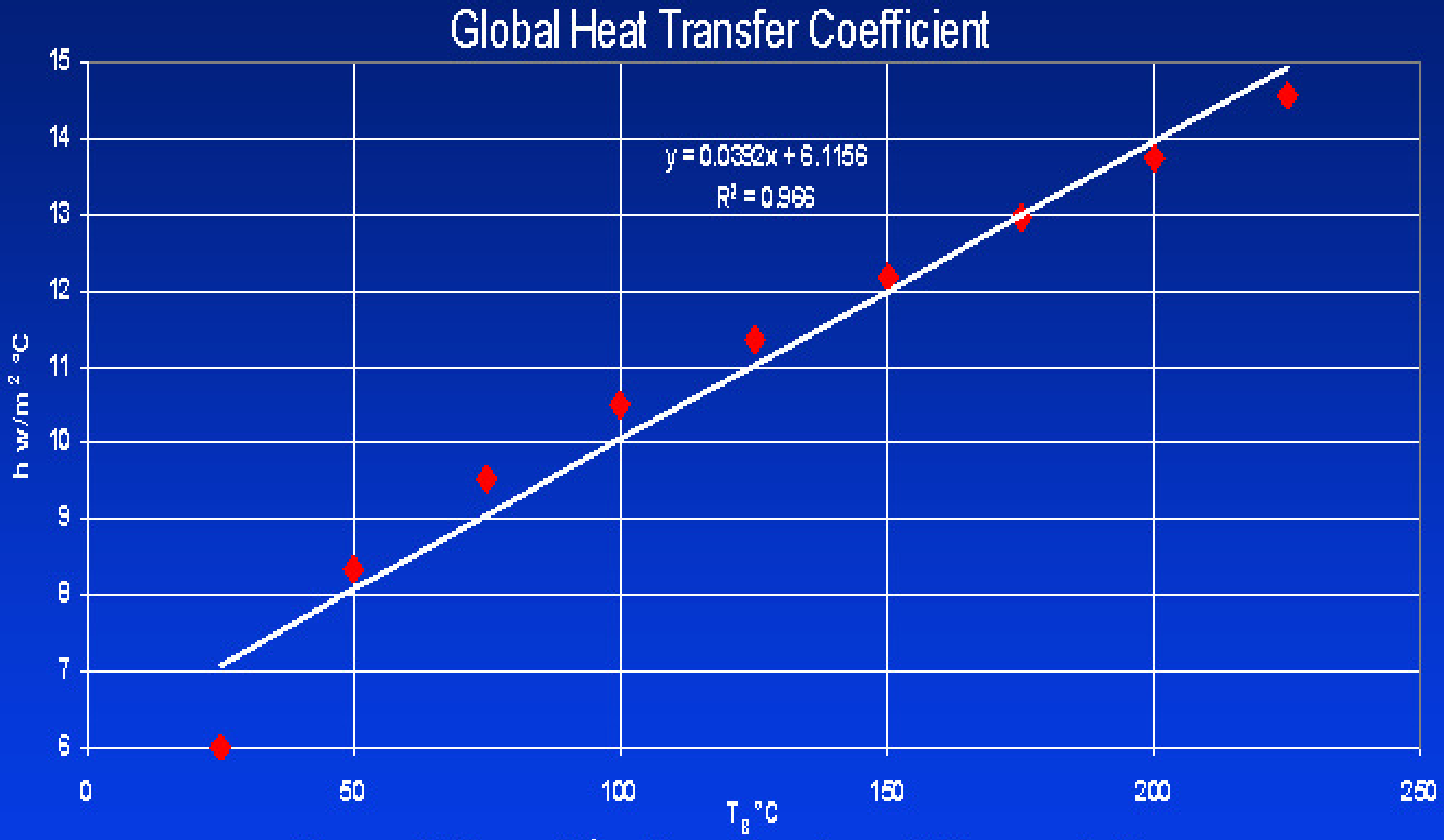
And finally, for horizontal surfaces facing down we have:

$$Nu = 0.27Ra^{\frac{1}{4}}, \text{ for } 3\times10^{5} \leq Ra \leq 3\times10^{10}$$

Where:

$$Ra = \frac{g\beta L^{3}(T_{B} - T_{air})}{\upsilon^{2}} \times \Pr$$

1D Busbar Heat Balance and Voltage Drop Equations



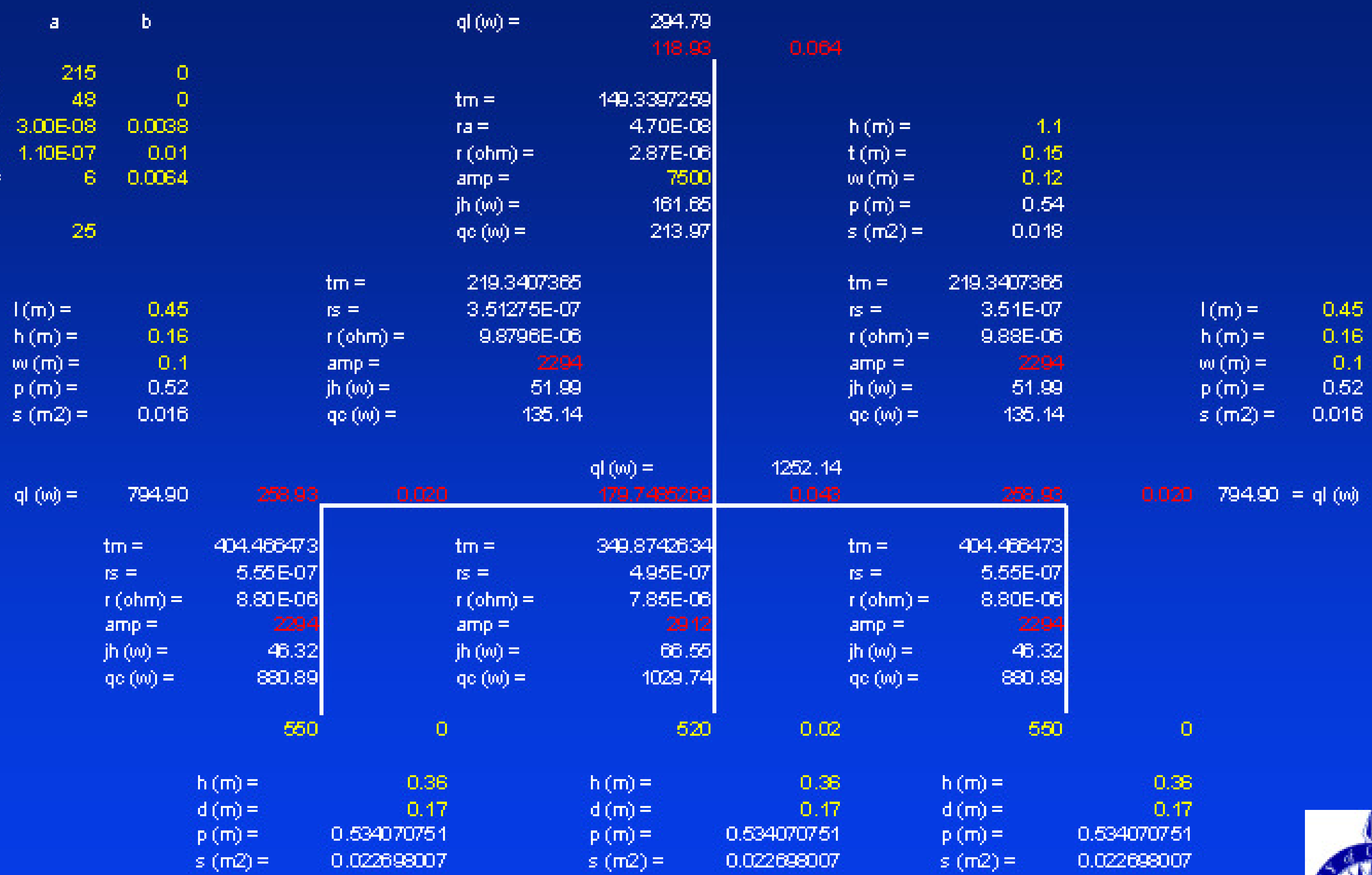
Curve fitting of h for one value of T_{air} and ε .

$$h(W/m^{2\circ}C) = h_0 \times (1 + \alpha_h \times T_B)$$

1D Busbar Heat Balance and Voltage Drop Equations

a*(1+b*T)	a	b
k a (w/mC) =	215	0
k s (w/mC) =	48	0
ra (ohm-m) =	3.00E-08	0.0038
rs (ohm-m) =	1.10E-07	0.01
h a (w/m2C) =	6	0.0064

Tair (C) = 25



ql (w) = 294.79
118.93 0.064

tm = 149.3397259
ra = 4.70E-08
r (ohm) = 2.87E-06
amp = 7500
jh (w) = 161.65
qc (w) = 213.97

h (m) = 1.1
t (m) = 0.15
w (m) = 0.12
p (m) = 0.54
s (m2) = 0.018

l (m) = 0.45
h (m) = 0.16
w (m) = 0.1
p (m) = 0.52
s (m2) = 0.016

tm = 219.3407365
rs = 3.51275E-07
r (ohm) = 9.8796E-06
amp = 2294
jh (w) = 51.99
qc (w) = 135.14

tm = 219.3407365
rs = 3.51E-07
r (ohm) = 9.88E-06
amp = 2294
jh (w) = 51.99
qc (w) = 135.14

l (m) = 0.45
h (m) = 0.16
w (m) = 0.1
p (m) = 0.52
s (m2) = 0.016

ql (w) = 1252.14

ql (w) = 794.90 258.93 0.020 179.7485269 0.043 258.93 0.020 794.90 = ql (w)

tm = 404.466473
rs = 5.55E-07
r (ohm) = 8.80E-06
amp = 2294
jh (w) = 46.32
qc (w) = 880.89

tm = 349.8742634
rs = 4.95E-07
r (ohm) = 7.85E-06
amp = 2912
jh (w) = 66.55
qc (w) = 1029.74

tm = 404.466473
rs = 5.55E-07
r (ohm) = 8.80E-06
amp = 2294
jh (w) = 46.32
qc (w) = 880.89

550 0 520 0.02 550 0

h (m) = 0.36
d (m) = 0.17
p (m) = 0.534070751
s (m2) = 0.022698007

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d (m) = 0.17
p (m) = 0.534070751
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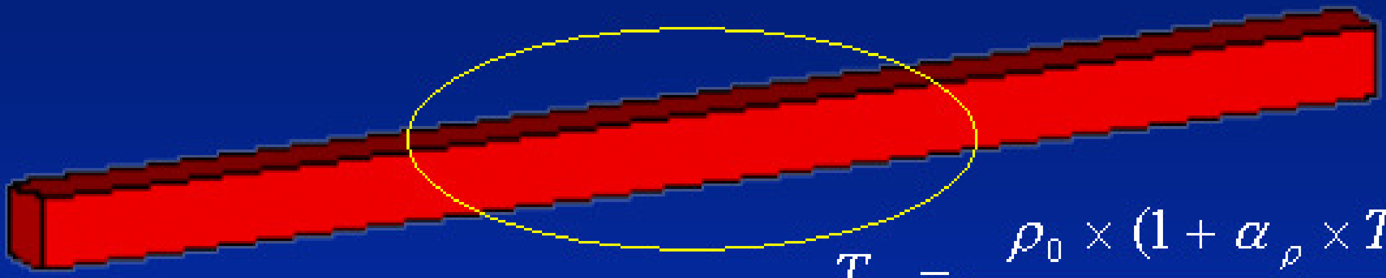
1D Busbar Heat Balance and Voltage Drop Equations



$$T_B = \frac{\rho_0 \times (1 + \alpha_\rho \times T_B) \times I^2}{h_0 \times (1 + \alpha_h \times T_B) \times P \times S} + T_{air}$$

In the case of a very long busbar of constant cross section, the temperature in the middle section of that busbar is define by the following equation:

By assigning some values to the 8 parameters involved,

T_B converges to 100 °C

$\rho_0 = 1E - 8$;

$\alpha_\rho = 0.0038$;

$h_0 = 6$;

$\alpha_h = 0.0064$;

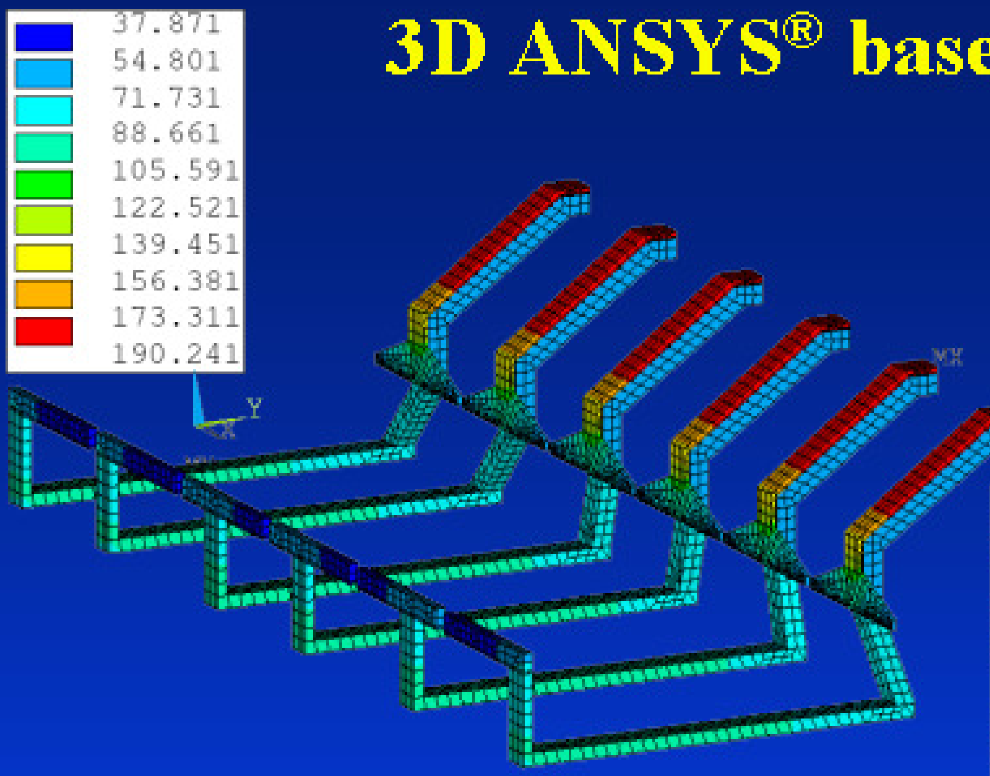
$S = 0.1$;

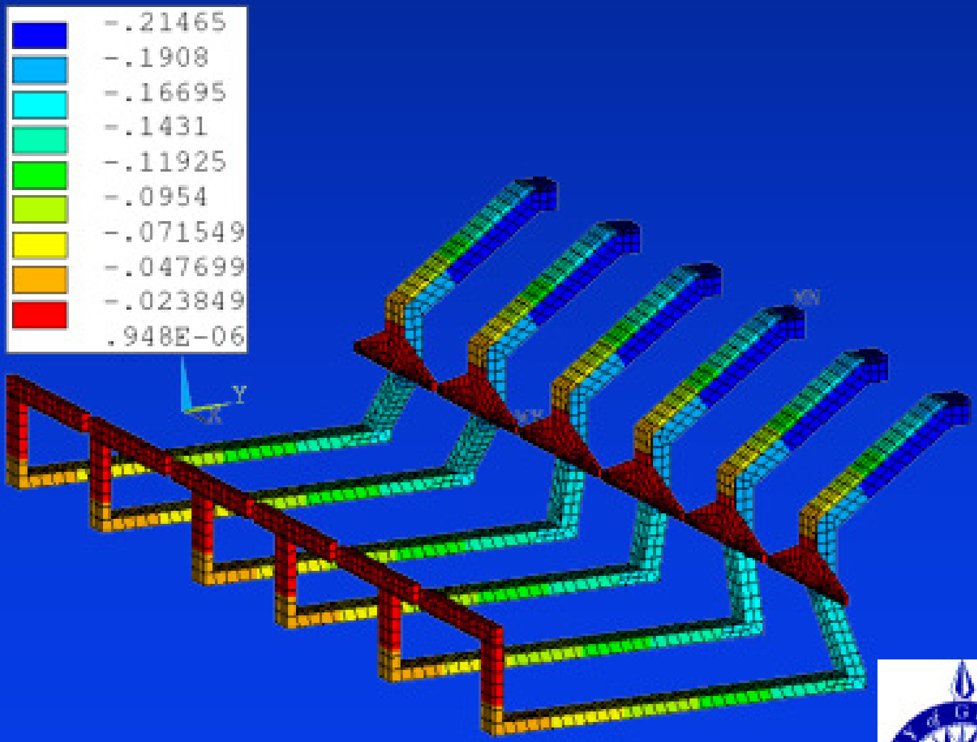
$P = 1.4$;

$I = 50000$;

$T_{ait} = 25$

3D ANSYS® based busbar model

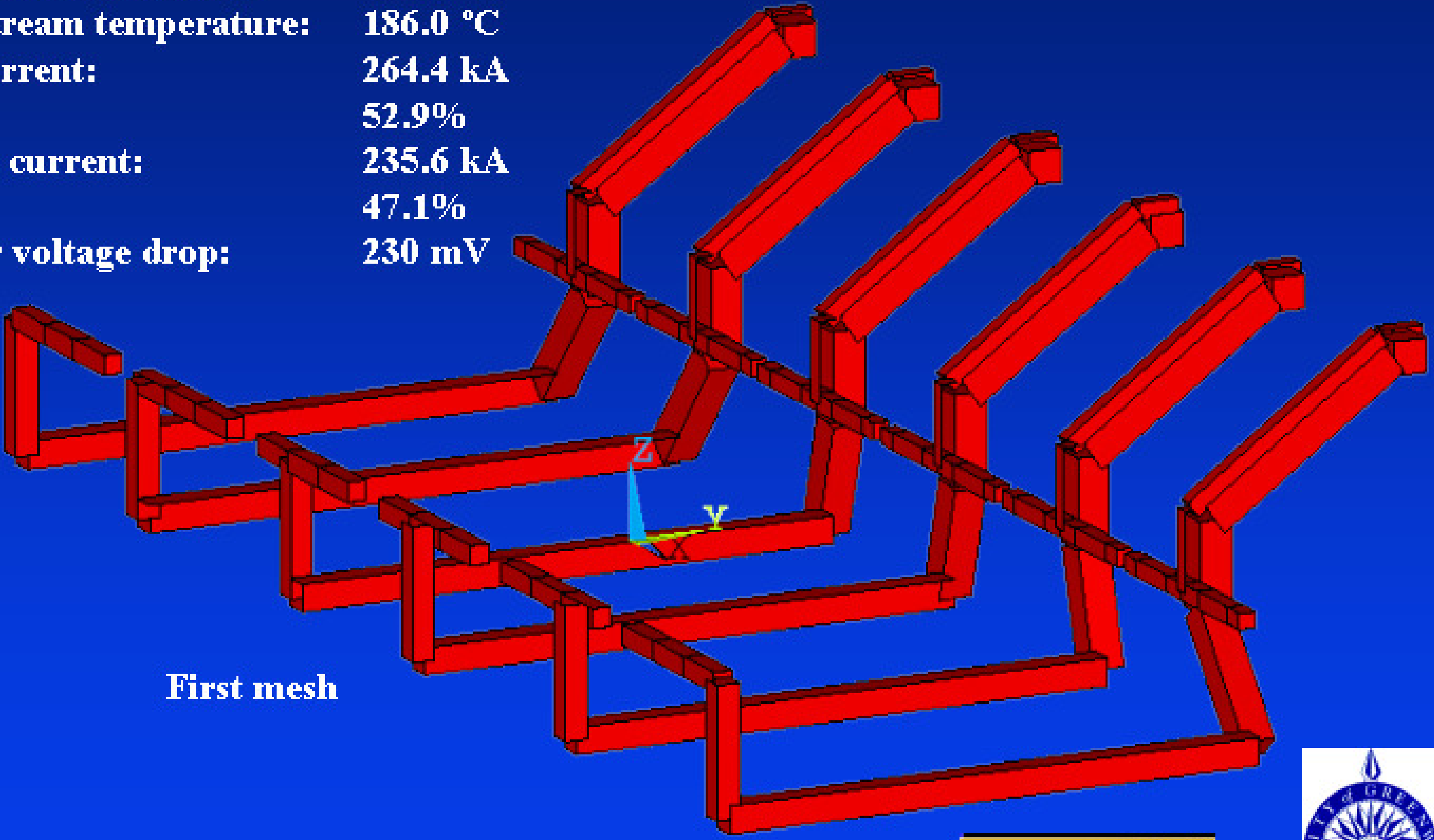




Max. upstream temperature: 95.1 °C
Max. downstream temperature: 190.2 °C
Upstream current: 256.7 kA
51.3%
Downstream current: 243.3 kA
48.7%
Total busbar voltage drop: 215 mV

1D ANSYS® based busbar model

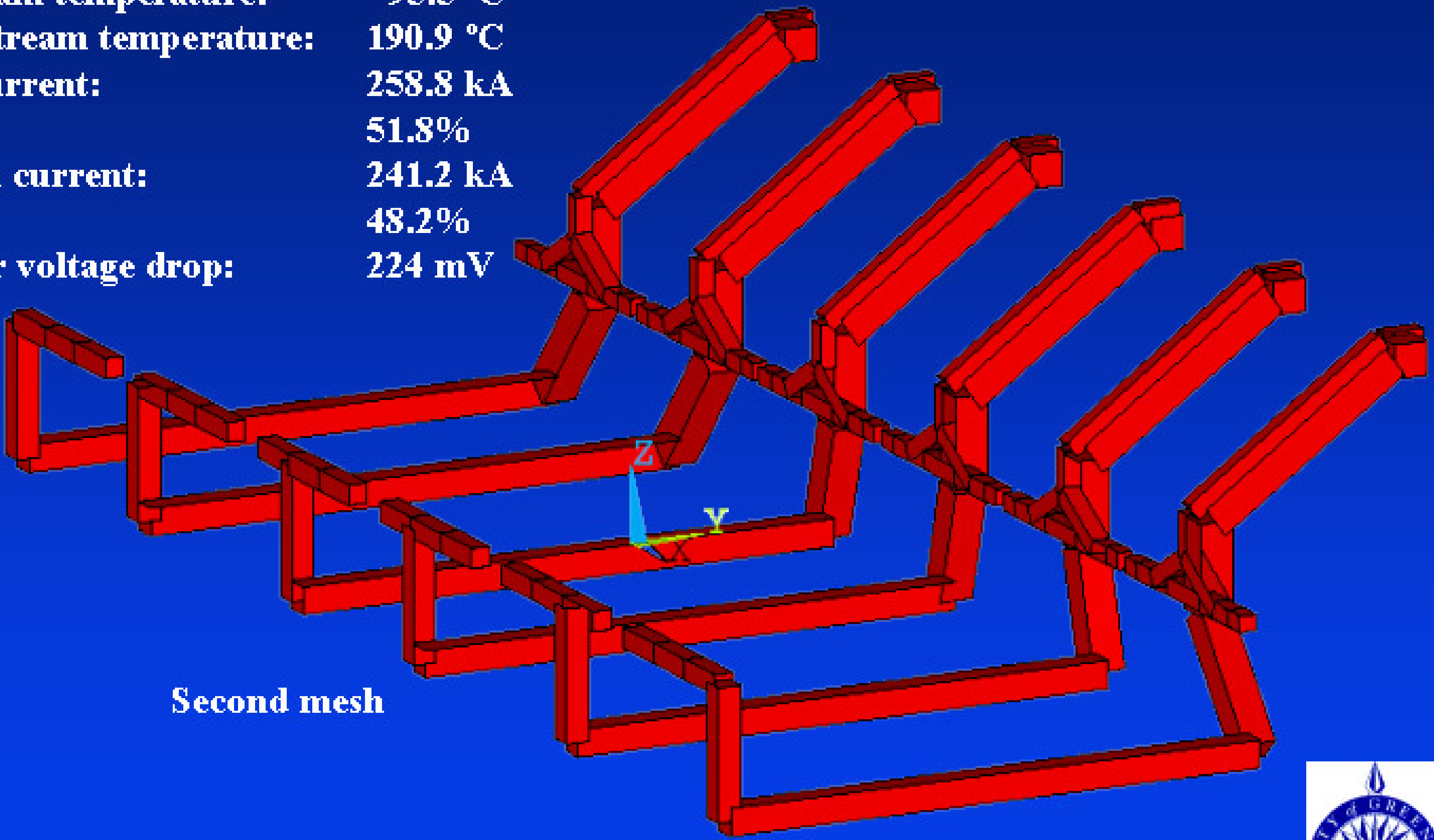
Max. upstream temperature:	98.4 °C
Max. downstream temperature:	186.0 °C
Upstream current:	264.4 kA 52.9%
Downstream current:	235.6 kA 47.1%
Total busbar voltage drop:	230 mV



First mesh

1D ANSYS® based busbar model

Max. upstream temperature:	95.5 °C
Max. downstream temperature:	190.9 °C
Upstream current:	258.8 kA
	51.8%
Downstream current:	241.2 kA
	48.2%
Total busbar voltage drop:	224 mV

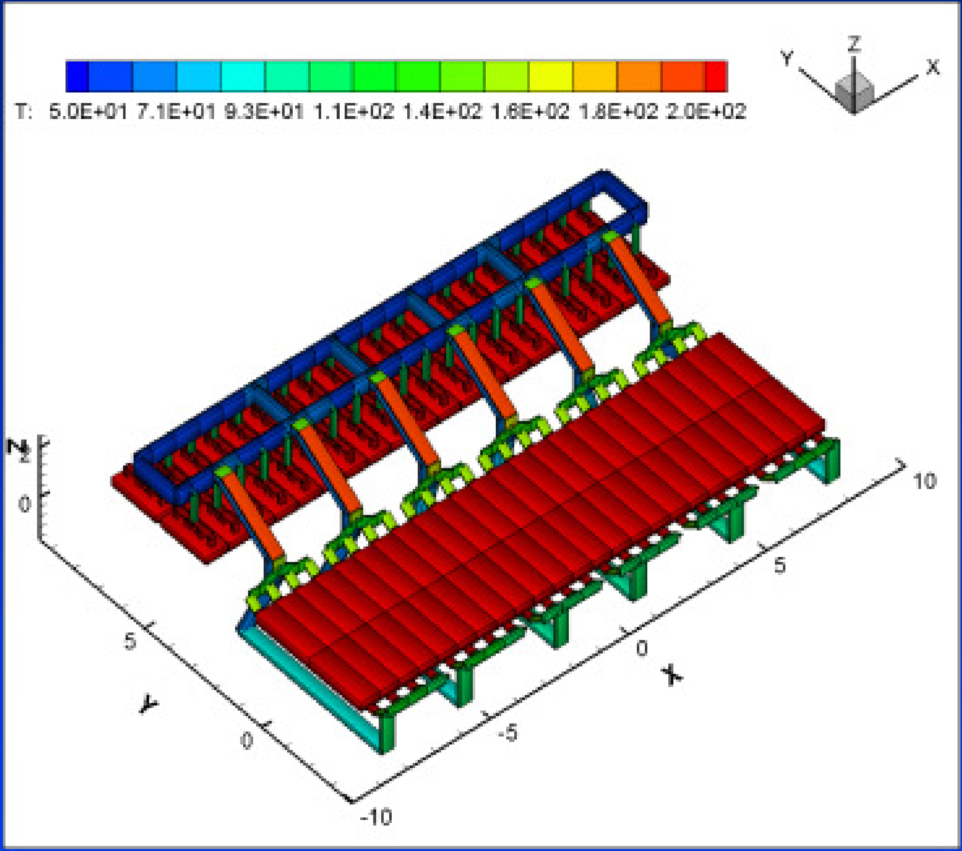


Second mesh

Versatile 1D busbar model part of MHD-Valdis

$$\sum_{n} \frac{k_m \cdot (T_m - T_n) \cdot S_m}{L_m} + h_m \cdot A_m \cdot (T_m - T_{air}) = R_m I_m^2$$

$$U_m \sum_{n=1}^{N} \frac{1}{R_n} - \sum_{n=1}^{N} \frac{U_n}{R_n} = I_m$$



Max. upstream temperature:	**94 °C**
Max. downstream temperature:	**197 °C**
Upstream current:	**253.0 kA**
	50.6%
Downstream current:	**247.0 kA**
	49.4%
Total busbar voltage drop:	**224 mV**

Conclusions

- It is not possible to reduce a given 3D busbar geometry into a 1D line elements network geometry without loosing some accuracy.
- The global heat transfer coefficient between the busbar external surfaces and its surrounding has a big impact on the busbar thermal balance .
- MHD-Valdis is the modeling tool recommended to carry out a busbar sizing optimization study because it is very efficient, versatile and user friendly .
- The maximum accuracy will be obtained by using an ANSYS® based 3D full cell and external busbar model, but that tool is not at all practical to carry out an optimization study .