

# Demonstration Thermo-Electric and MHD Mathematical Models of a 500 kA Al Electrolysis Cell

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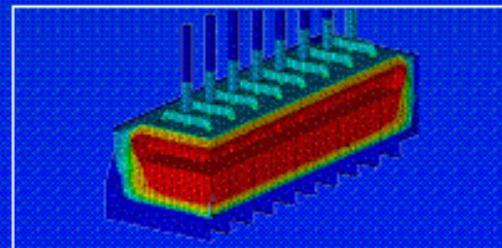
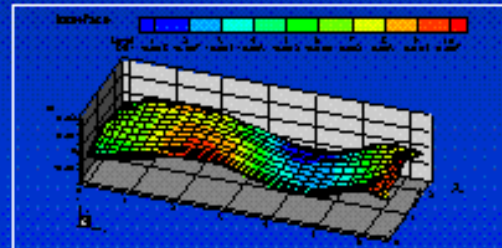
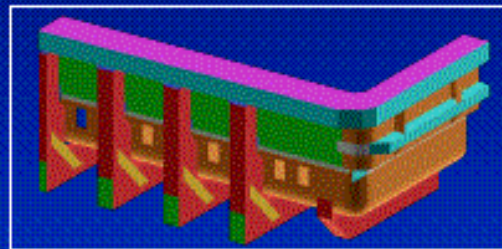
# Plan of the Presentation

- **Introduction**
- **Part 1: Dupuis' Thermo-Electric Models**
  - **Lump Parameters+ Cell Heat Balance Model**
  - **3D Full Cell Side Slice Thermo-Electric Model**
  - **Complete Full Cell Quarter Thermo-Electric Model**
- **Part 2: Bojarevics' Cell Stability Model**
- **Conclusions**
- **Future Developments**

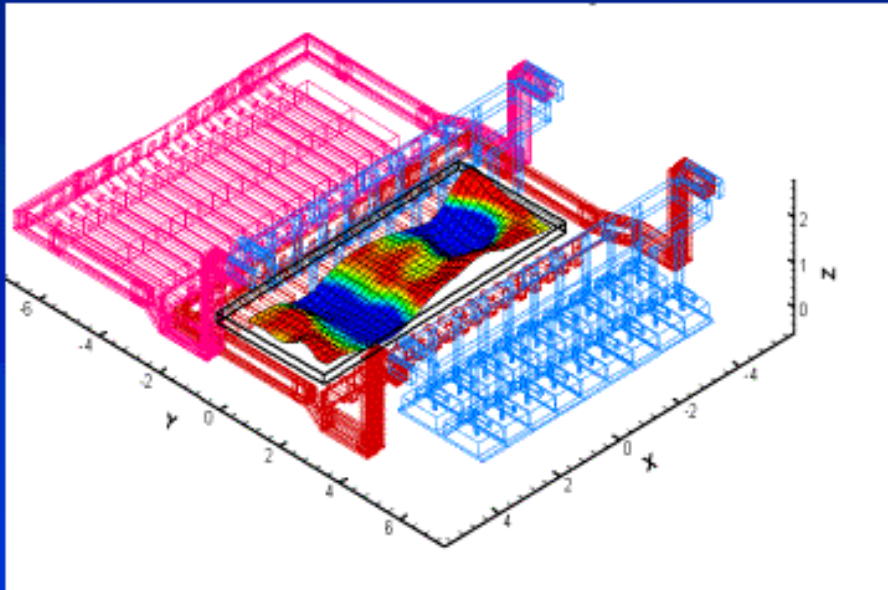
# Modeling the Hall-Héroult Cell

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

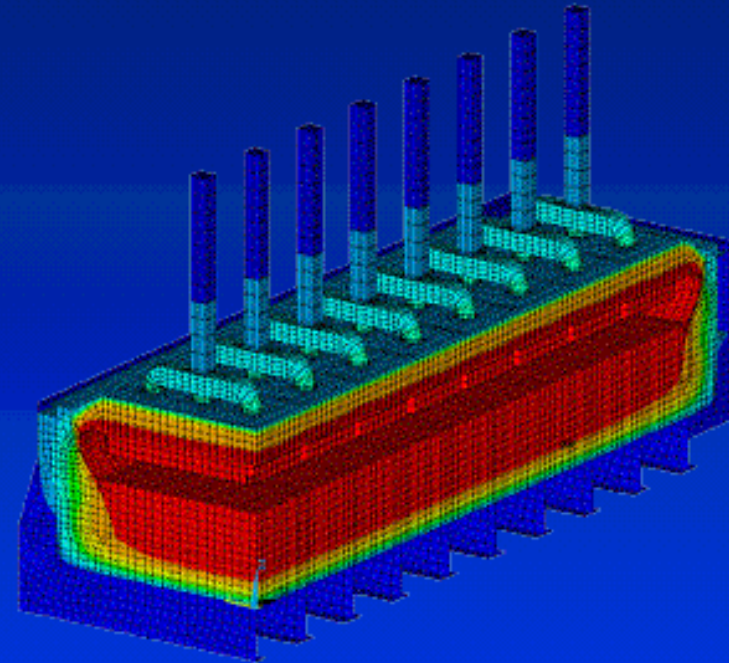
- Stress models which are generally associated with cell shell deformation and cathode heaving issues.
- Magneto-hydro-dynamic (MHD) models which are generally associated with the problem of cell stability.
- Thermal-electric models which are generally associated with the problem of cell heat balance.



# Modeling the Hall-Héroult Cell



**MHD model:**  
centered around the liquid zone



**Thermo-electric model:**  
no need to include the liquid zone

# Thermo-Electric Design of a 500 kA cell Using a Lump Parameter+ model

DYNA/MARC 1.7 - [VAM016]

File Process Control Operator View List Windows Language Help

Demo example of a prebaked PBF cell inspired from VAM's JCM paper  
 liquidus superheat, 4 cm ACD, 1.95m anode length, 13.5% AlF<sub>3</sub>, 500 kA  
 MC10 4.17m cathode block, top 10cm bottom 16.5 cm SiC side block  
 10 cm cover over anodes, 17.5 cm stud diameter, 4 studs per anode  
 40 anodes, 24 cathode blocks, 17.8 m X 4.85 m inside potshell

Date Created : 8/2/1999 Last Modified : 9/15/2002

Steady State Solution

Cell amperage	500.0 [kA]
Anode to cathode distance	4.00000 [cm]
Operating temperature	963.366 [C]
Ledge thickness, bath level	4.44079 [cm]
Ledge thickness, metal level	0.16550 [cm]
Anode beam position	0.0000 [cm]
Mass of metal	33763.7 [kg]
Mass of bath	11020.16 [kg]
Mass of dissolved alumina	275.504 [kg]
Mass of dispersed alumina	79.390 [kg]
Mass of alumina sludge	2.5966 [kg]
Mass of dissolved aluminum fluoride	1487.722 [kg]
Mass of dispersed aluminum fluoride	1.015 [kg]
Mass of aluminum fluoride sludge	0.0003 [kg]
Mass of calcium fluoride	330.603 [kg]
Mass of lithium fluoride	0.000 [kg]
Mass of magnesium fluoride	0.000 [kg]
Alumina feeding rate	310.010 [kg/hr]
Aluminum fluoride feeding rate	3.07019 [kg/hr]
Target cell resistance	5.31686 [micro-ohm]

Steady State derived Variables

Rate of change of:	
ACD	-0.02224 [cm/hr]
Operating temperature	0.000 [C/hr]
Ledge thickness, bath level	0.000 [cm/hr]
Ledge thickness, metal level	0.000 [cm/hr]
Mass of dispersed Al <sub>2</sub> O <sub>3</sub>	0.000 [kg/hr]

DYNA/MARC: Winc II

List of Design Variables

	Design Value		Set as Target
Anode to Cathode Distance	4	cm	<input type="checkbox"/>
Cell Amperage	500	kA	<input type="checkbox"/>
Conc. of Excess Aluminum Fluoride	13.5	%	<input type="checkbox"/>
Concentration of Dissolved Alumina	2.5	%	<input type="checkbox"/>
Concentration of Calcium Fluoride	3	%	<input type="checkbox"/>
Concentration of Lithium Fluoride	0	%	<input type="checkbox"/>
Conc. of Magnesium Fluoride	0	%	<input type="checkbox"/>
Bath Level	20	cm	<input type="checkbox"/>
Bath Ledge Heat Transfer Coef.	1425	W/m <sup>2</sup> C	<input type="checkbox"/>
Metal Ledge Heat Transfer Coef.	2052	W/m <sup>2</sup> C	<input type="checkbox"/>
Metal Level	20	cm	<input type="checkbox"/>
Anode Length	1.95	m	<input type="checkbox"/>
Cavity Length	17.48	m	<input type="checkbox"/>
Anode Panel Heat Loss	293.971843	kW	Advanced <input type="checkbox"/>
Cathode Bottom Heat Loss	237.657447	kW	Advanced <input type="checkbox"/>
Cell Operating Temperature	963.366000	C	<input checked="" type="checkbox"/>
Anode Voltage Drop	319.513746	V	Advanced <input type="checkbox"/>
Cathode Voltage Drop	311.955304	V	Advanced <input type="checkbox"/>
Anode Width	0.8	m	<input type="checkbox"/>
Cavity Width	4.55	m	<input type="checkbox"/>

Run Exit

Press F1 for Help Demo example of a prebaked PBF cell inspired from VAM's JCM paper 10/3/2002 2:08 PM CAPS NUM BASEP

# Thermo-Electric Design of a 500 kA cell

## Using a Lump Parameter+ model (from 300 to 400 kA)

	Base case	Step 1	Step 2	Step 3	Step 4-5	Step 6-7	Step 8	Step 9	Step 10
Modeling tool	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7
Amperage	300kA	<b>322 kA</b>	<b>330 kA</b>	330kA	330kA	330kA	<b>335 kA</b>	<b>350 kA</b>	<b>400 kA</b>
Nb. of anodes	32	32	32	32	32	32	32	32	<b>36</b>
Anode size	1.6 m X 0.8 m	1.6 m X 0.8 m	<b>1.7 m X 0.8 m</b>	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m
Nb. of anode studs	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode
Anode stud diameter	18 cm	18 cm	18 cm	18 cm	18 cm	18 cm	18 cm	<b>19 cm</b>	19 cm
Anode cover thickness	16 cm	16 cm	16 cm	16 cm	16 cm	16 cm	<b>10 cm</b>	10 cm	10 cm
Nb. of cathode blocks	18	18	18	18	18	18	18	18	<b>20</b>
Cathode block length	3.47 m	3.47 m	3.47 m	3.47 m	<b>3.67 m</b>	3.67 m	3.67 m	3.67 m	3.67 m
Type of cathode block	H03	H03	H03	H03	<b>H010</b>	H010	H010	H010	H010
Type of side block	H03	H03	H03	H03	H03	<b>SiC</b>	SiC	SiC	SiC
Side block thickness	15 cm +	15 cm +	15 cm +	15 cm +	15 cm +	<b>10 cm +</b>	10 cm +	10 cm +	10 cm +
ASD	35 cm	35 cm	<b>25 cm</b>	25 cm	25 cm	<b>30 cm</b>	30 cm	30 cm	30 cm
Insule potshell size	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	<b>16.1 X 4.35 m</b>
ACD	5 cm	<b>4 cm</b>	4 cm	4 cm	4 cm	4 cm	4 cm	4 cm	4 cm
Excess AlF <sub>3</sub>	10.9 %	10.9 %	10.9 %	<b>13.5 %</b>	13.5 %	13.5 %	13.5 %	13.5 %	13.5 %
Anode drop	306 mV	<b>325 mV</b>	<b>328 mV</b>	328 mV	328 mV	328 mV	<b>331 mV</b>	<b>330 mV</b>	335 mV
Cathode drop	290 mV	<b>311 mV</b>	<b>319 mV</b>	319 mV	<b>277 mV</b>	277 mV	<b>281 mV</b>	<b>293 mV</b>	301 mV
Anode panel heat loss	239 kW	<b>244 kW</b>	<b>247 kW</b>	247 kW	<b>247 kW</b>	<b>250 kW</b>	<b>275 kW</b>	<b>284 kW</b>	311 kW
Cathode bottom heat loss	166 kW	<b>167 kW</b>	<b>168 kW</b>	168 kW	<b>171 kW</b>	171 kW	<b>172 kW</b>	<b>173 kW</b>	193 kW
Operating temperature	973.3 °C	973.3 °C	973.3 °C	<b>960.8 °C</b>	<b>960.3 °C</b>	<b>960.2 °C</b>	<b>960.0 °C</b>	<b>961.5 °C</b>	<b>962.7 °C</b>
Liquitus superheat	6.8 °C	6.8 °C	6.8 °C	<b>7.2 °C</b>	<b>6.6 °C</b>	<b>6.5 °C</b>	<b>6.3 °C</b>	<b>7.8 °C</b>	<b>9.0 °C</b>
Bath ledge fluidness	7.61 cm	<b>7.75 cm</b>	<b>7.71 cm</b>	<b>6.85 cm</b>	<b>7.81 cm</b>	<b>9.02 cm</b>	<b>9.34 cm</b>	<b>6.69 cm</b>	<b>5.11 cm</b>
Metal ledge fluidness	2.79 cm	<b>2.93 cm</b>	<b>2.88 cm</b>	<b>2.03 cm</b>	<b>2.98 cm</b>	<b>4.75 cm</b>	<b>5.07 cm</b>	<b>2.42 cm</b>	<b>0.83 cm</b>
Current efficiency	94.0 %	<b>94.4 %</b>	<b>94.2 %</b>	<b>95.9 %</b>	<b>95.9 %</b>	<b>95.9 %</b>	<b>96.0 %</b>	<b>96.0 %</b>	<b>96.0 %</b>
Internal heat	628 kW	<b>633 kW</b>	<b>637 kW</b>	<b>647 kW</b>	<b>633 kW</b>	<b>633 kW</b>	<b>652 kW</b>	<b>712 kW</b>	<b>825 kW</b>
Energy consumption	13.75 kWh/kg	<b>13.32 kWh/kg</b>	<b>13.20 kWh/kg</b>	<b>13.14 kWh/kg</b>	<b>13.01 kWh/kg</b>	<b>13.00 kWh/kg</b>	<b>13.10 kWh/kg</b>	<b>13.37 kWh/kg</b>	<b>13.4 kWh/kg</b>

# Thermo-Electric Design of a 500 kA cell Using a Lump Parameter+ model (from 400 to 500 kA)

	Base case	Step 1	Step 2	Step 3	Step 4
Modeling tool	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7
Amperage	400 kA	<b>440 kA</b>	<b>480 kA</b>	<b>490 kA</b>	<b>500 kA</b>
Nb. of anodes	36	<b>40</b>	40	40	40
Anode size	1.7 m X 0.8 m	1.7 m X 0.8 m	<b>1.95 m X 0.8 m</b>	1.95 m X 0.8 m	1.95 m X 0.8 m
Nb. of anode studs	3 per anode	3 per anode	3 per anode	<b>4 per anode</b>	4 per anode
Anode stud diameter	19 cm	19 cm	19 cm	<b>17.5 cm</b>	17.5 cm
Anode cover thickness	10 cm	10 cm	10 cm	10 cm	10 cm
Nb. of cathode blocks	20	<b>22</b>	22	22	<b>24</b>
Cathode block length	3.67 m	3.67 m	<b>4.17 m</b>	4.17 m	4.17 m
Type of cathode block	HC10	HC10	HC10	HC10	HC10
Type of side block	SiC	SiC	SiC	SiC	SiC
Side block thickness	10 cm +	10 cm +	10 cm +	10 cm +	10 cm +
ASD	30 cm	30 cm	30 cm	30 cm	30 cm
Inside potshell size	16.1 X 4.35 m	<b>17.8 X 4.35 m</b>	<b>17.8 X 4.85 m</b>	17.8 X 4.85 m	17.8 X 4.85 m
ACD	4 cm	4 cm	4 cm	4 cm	4 cm
Excess AlF <sub>3</sub>	13.5 %	13.5 %	13.5 %	13.5 %	13.5 %
Anode drop	335 mV	<b>332 mV</b>	<b>347 mV</b>	<b>314 mV</b>	<b>320 mV</b>
Cathode drop	301 mV	<b>331 mV</b>	<b>324 mV</b>	<b>331 mV</b>	<b>312 mV</b>
Anode panel heat loss	311 kW	<b>335 kW</b>	<b>367 kW</b>	<b>391 kW</b>	<b>394 kW</b>
Cathode bottom heat loss	193 kW	<b>202 kW</b>	<b>231 kW</b>	<b>231 kW</b>	<b>238 kW</b>
Operating temperature	962.7 °C	<b>963.4 °C</b>	<b>962.8 °C</b>	962.8 °C	<b>963.4 °C</b>
Liquidus superheat	9.0 °C	<b>9.7 °C</b>	<b>9.1 °C</b>	9.1 °C	<b>9.7 °C</b>
Bath ledge thickness	5.11 cm	<b>4.43 cm</b>	<b>4.97 cm</b>	<b>4.99 cm</b>	<b>4.44 cm</b>
Metal ledge thickness	0.83 cm	<b>0.15 cm</b>	<b>0.70 cm</b>	<b>0.71 cm</b>	<b>0.17 cm</b>
Current efficiency	96.0 %	<b>95.9 %</b>	<b>95.8 %</b>	<b>95.9 %</b>	95.9 %
Internal heat	825 kW	<b>916 kW</b>	<b>964 kW</b>	<b>988 kW</b>	<b>1019 kW</b>
Energy consumption	13.49 kWh/kg	<b>13.53 kWh/kg</b>	<b>13.31 kWh/kg</b>	<b>13.33 kWh/kg</b>	<b>13.39 kWh/kg</b>

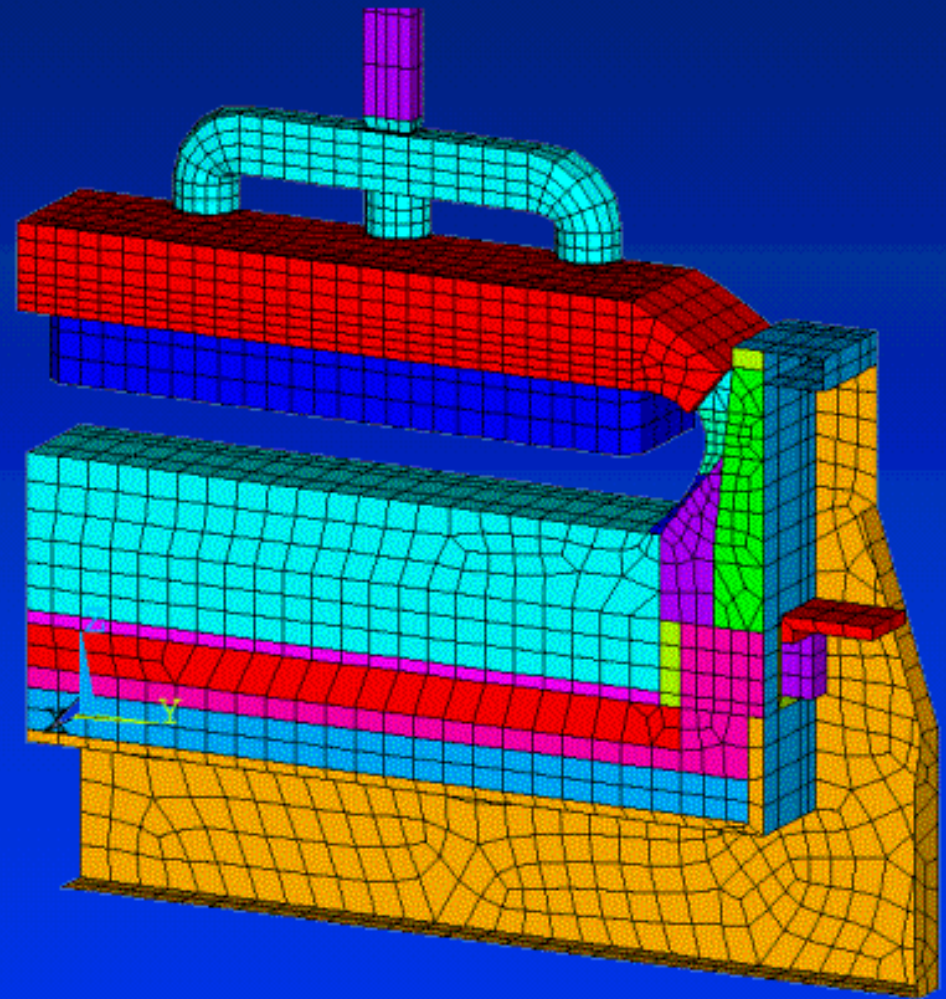
# Thermo-Electric Design of a 500 kA cell Using a 3D Full Cell Side Slice Thermo-Electric Model

## 500 kA Demonstration Cell Key Characteristics

Inside potshell size:	17.8 m x 4.85 m
Anode size:	1.95 m x 0.8 m
Number of anodes:	40
Anodic current density:	0.80 A/cm <sup>2</sup>
Cathode block size:	4.17 m x 0.66 m x 0.48 m
Cathode block type:	HC10
Side block type:	SiC
Number of anodic risers:	6

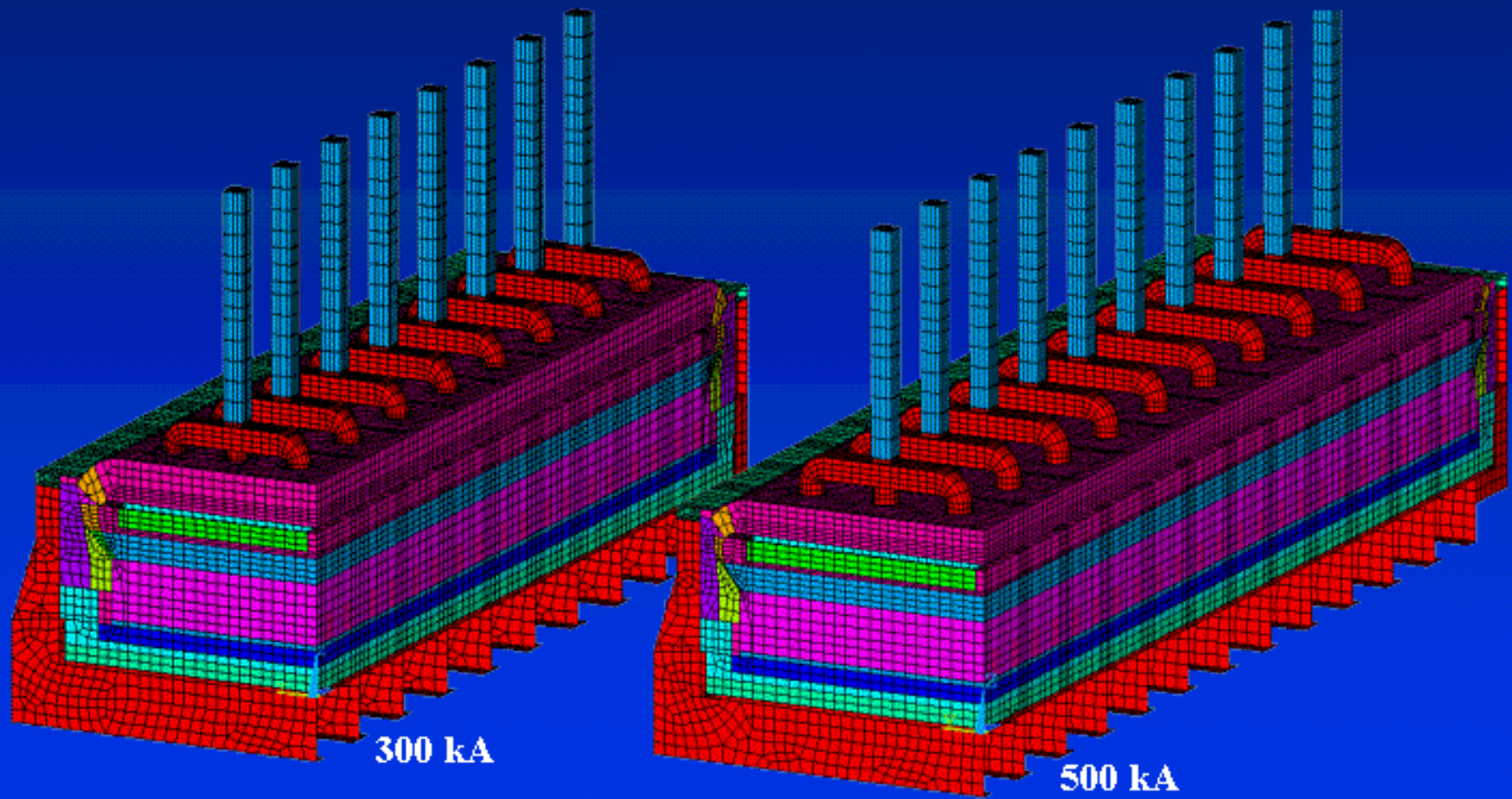
## 3D Full Cell Side Slice T-E Model's Key Results

Anode drop:	354 mV
Cathode drop:	314 mV
Anode panel heat loss:	409 kW
Total cathode heat loss:	633 kW
Operating temperature:	963.1 °C
Liquidus superheat:	9.4 °C
Average ledge thickness at bath level:	2.42 cm
Average ledge thickness at metal level:	6.15 cm
Cell internal heat:	1043 kW
Energy consumption:	13.61 kWh/kg

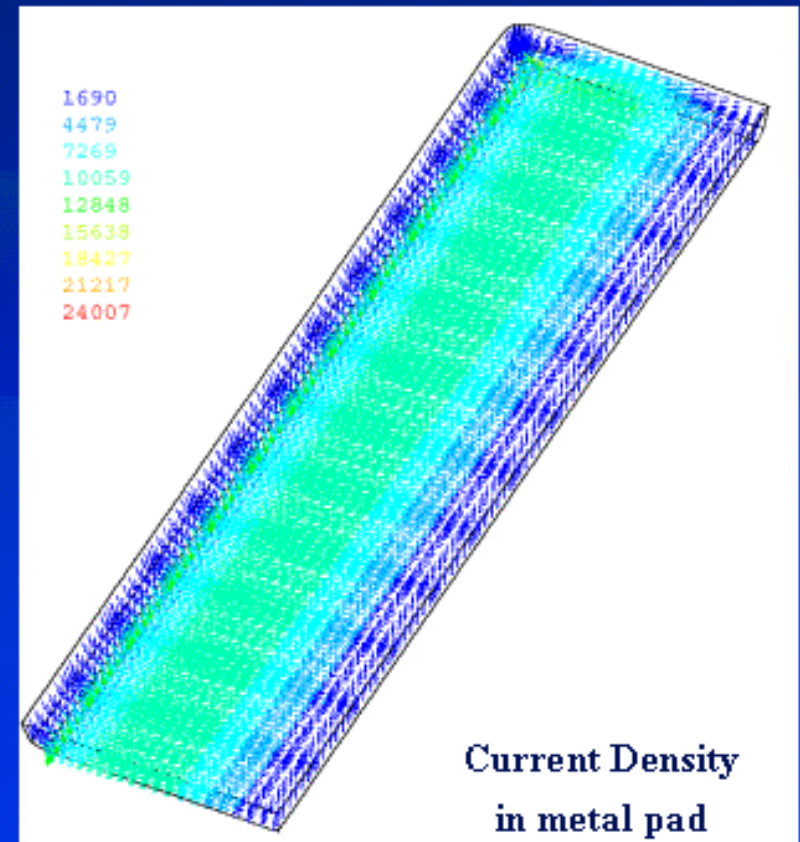
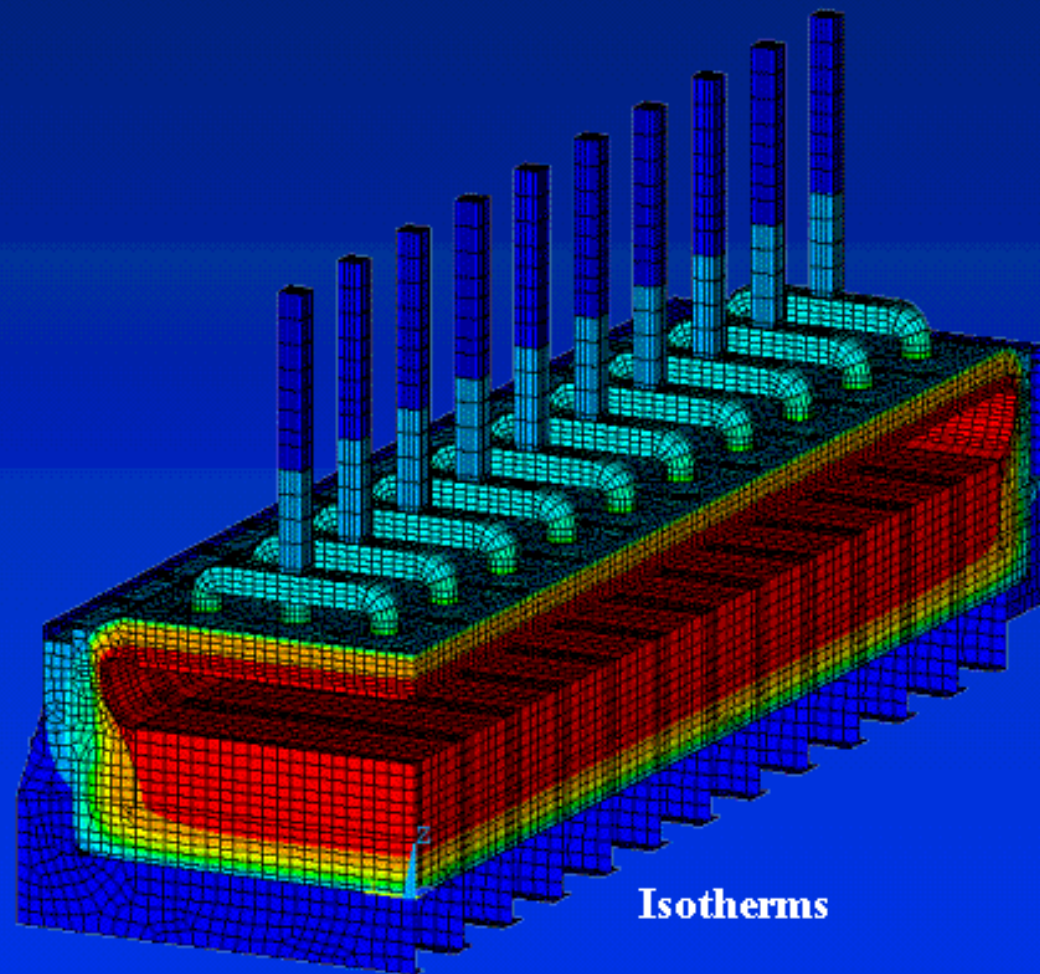




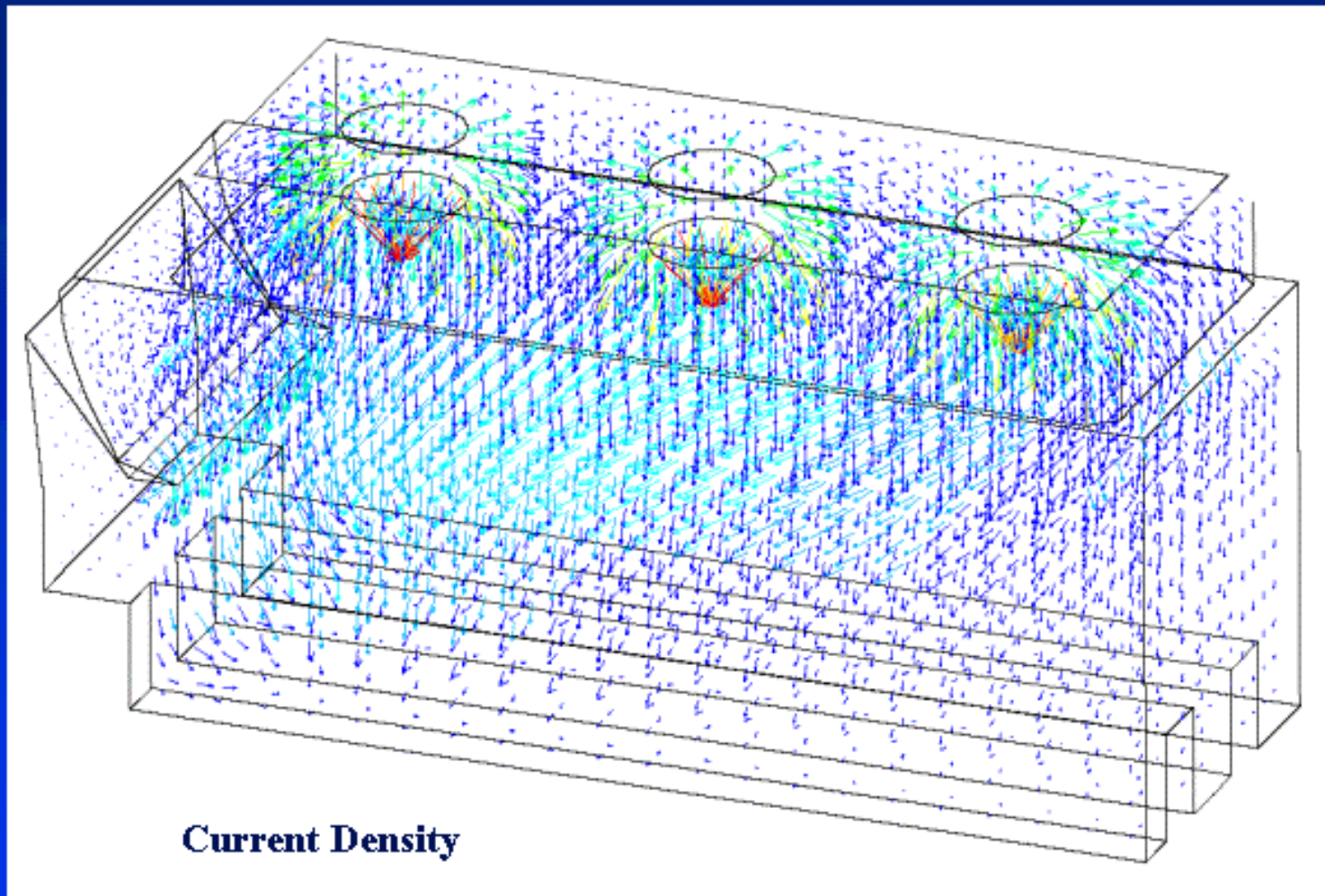
# Thermo-Electric Design of a 500 kA cell Using a Complete Full Cell Quarter Thermo-Electric Model



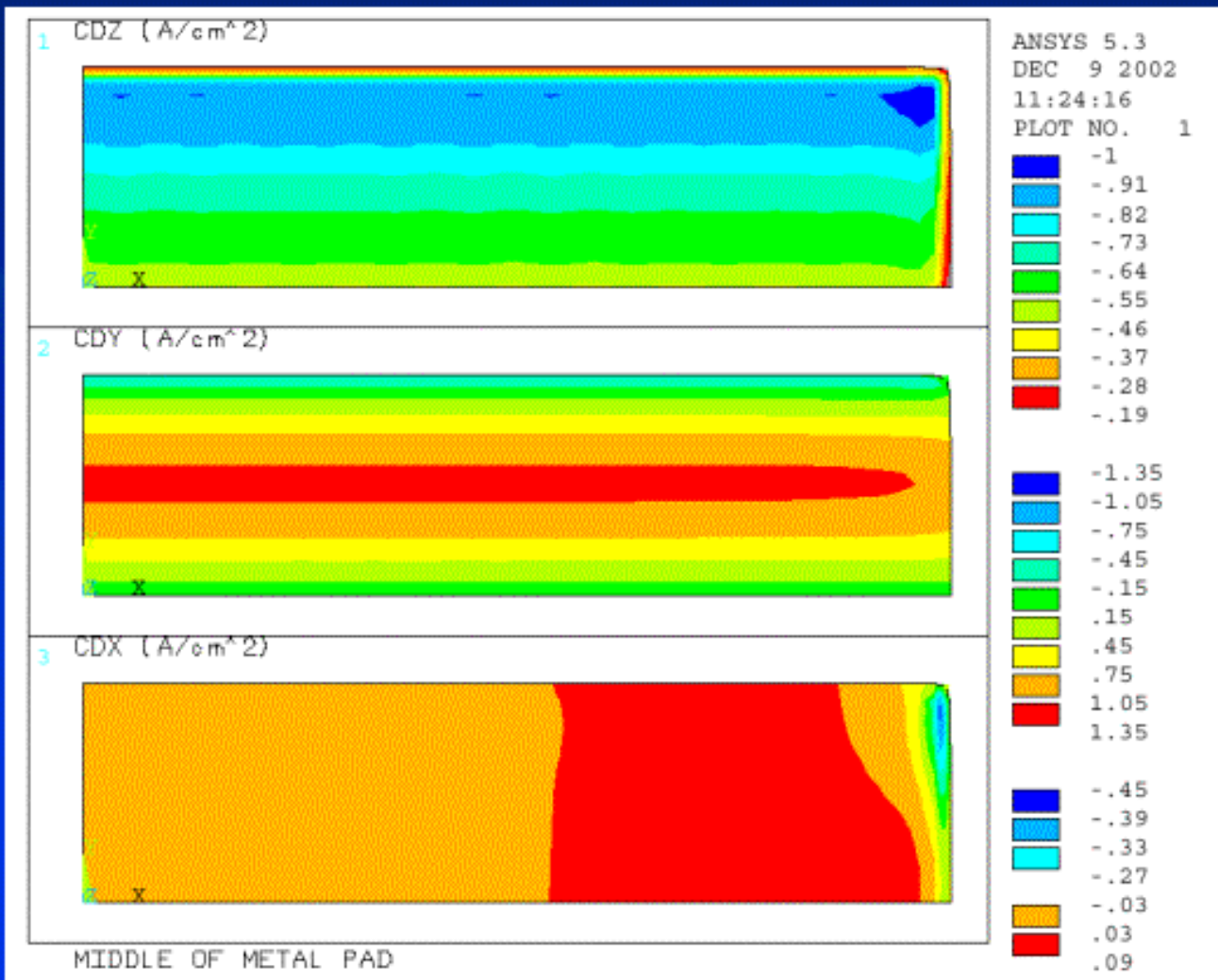
# Thermo-Electric Design of a 500 kA cell Using a Complete Full Cell Quarter Thermo-Electric Model



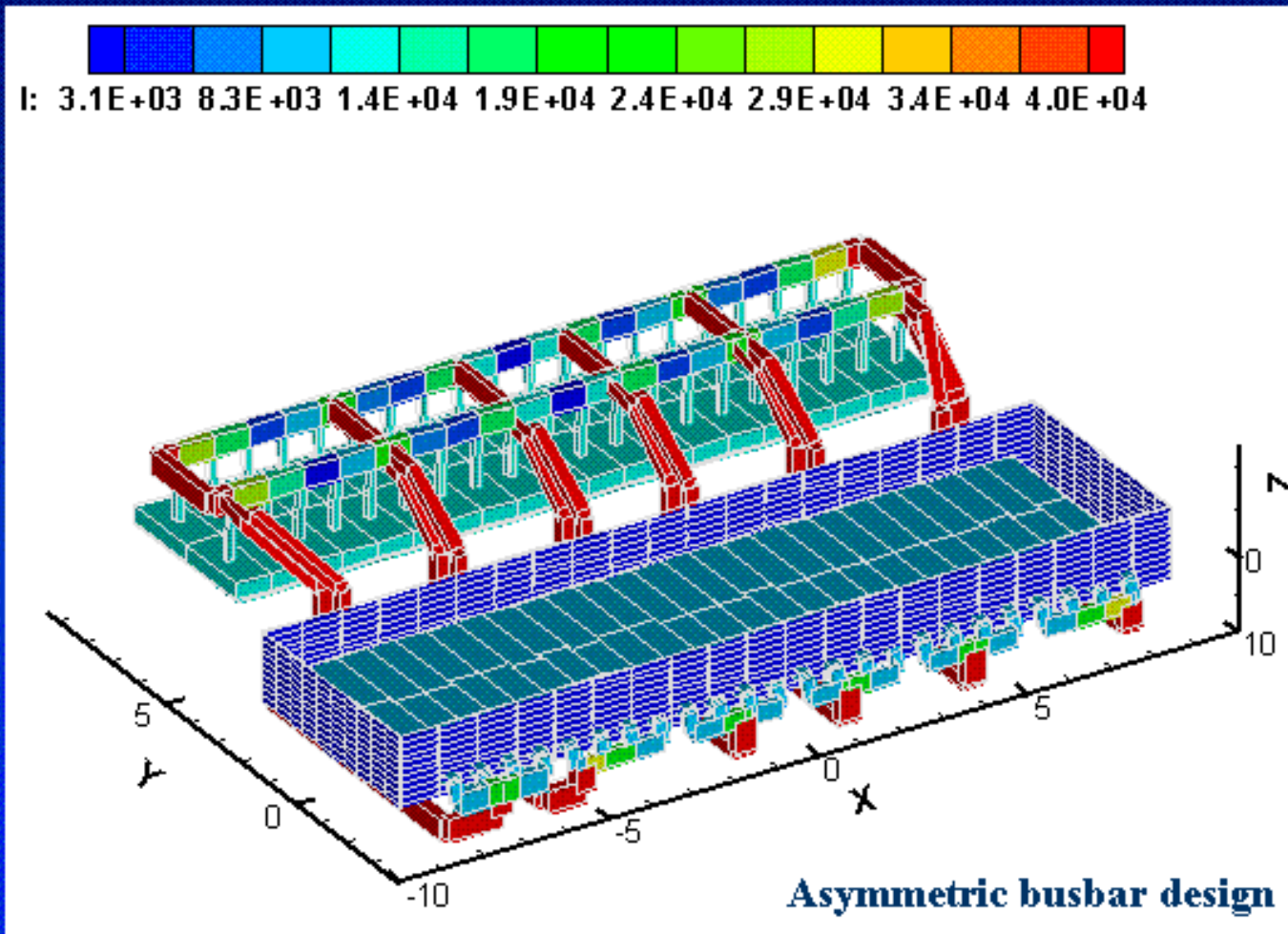
# Thermo-Electric Design of a 500 kA cell Using a Complete Full Cell Quarter Thermo-Electric Model



# Thermo-Electric Design of a 500 kA cell Using a Complete Full Cell Quarter Thermo-Electric Model

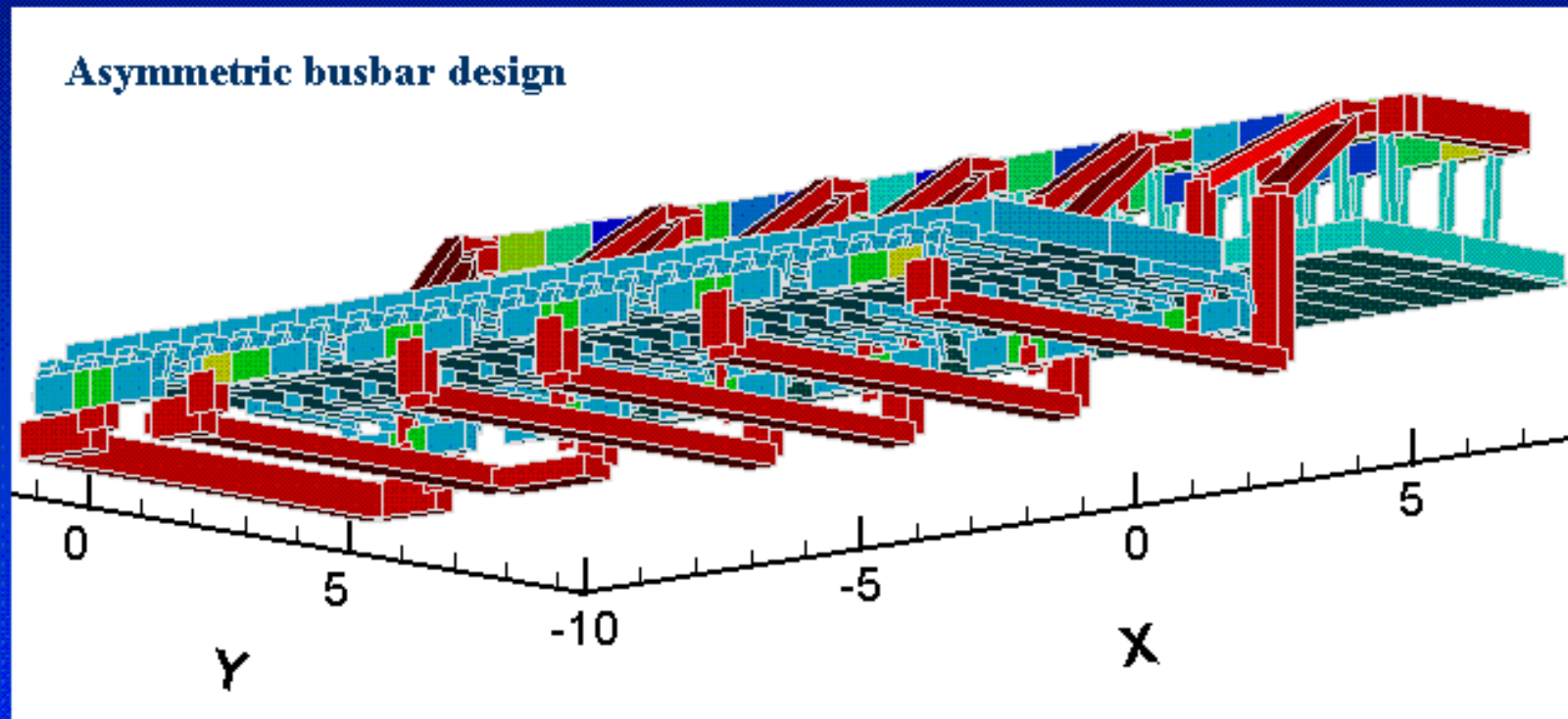


# MHD Design of a 500 kA cell Using Bojarevics' Cell Stability Model

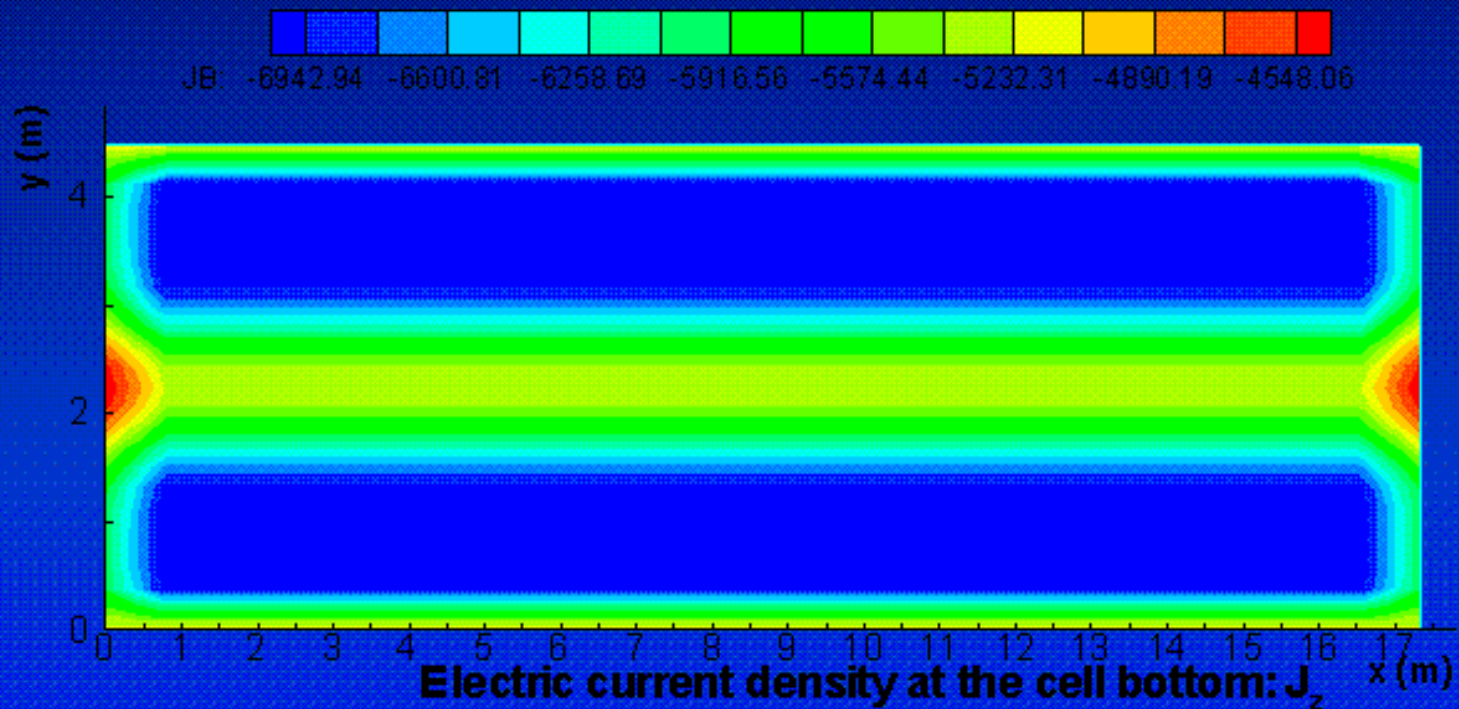


# MHD Design of a 500 kA cell Using Bojarevics' Cell Stability Model

Asymmetric busbar design



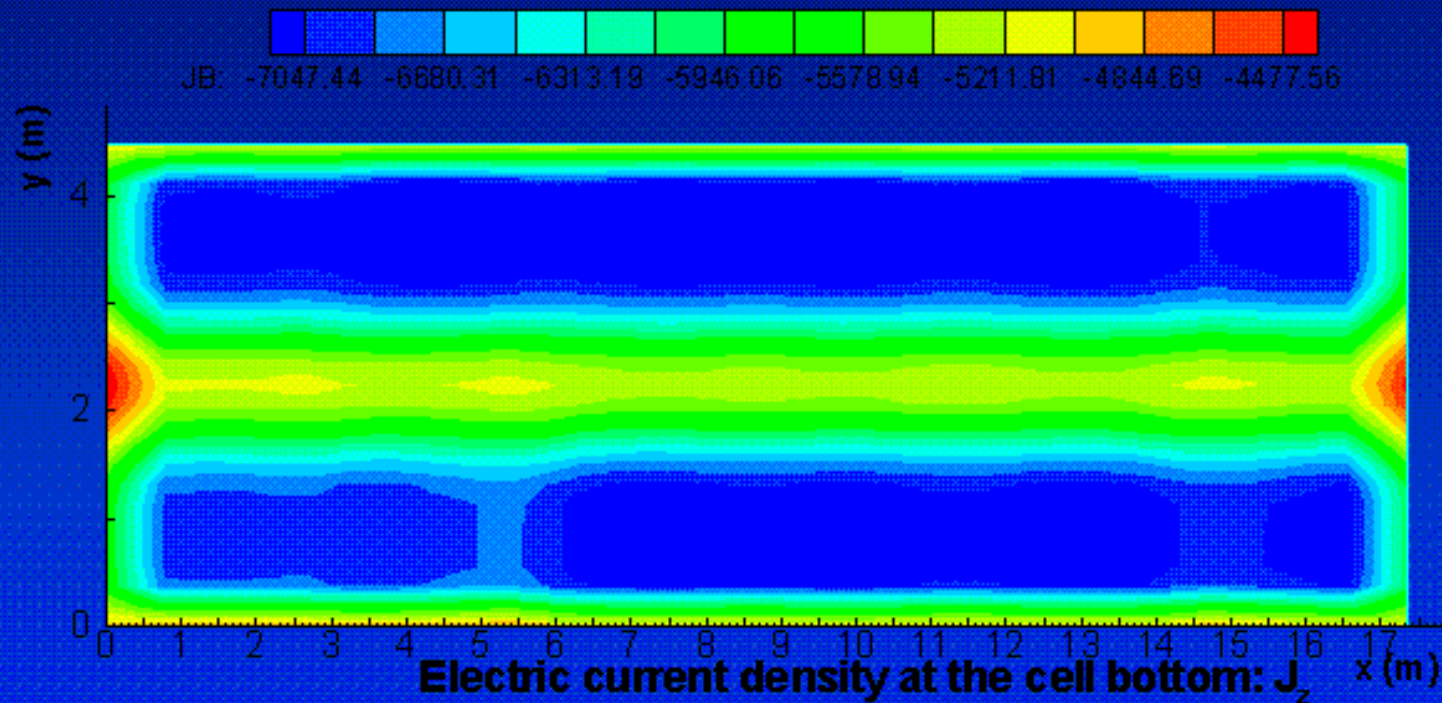
# MHD Design of a 500 kA cell Using Bojarevics' Cell Stability Model



Uniform current pickup

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# MHD Design of a 500 kA cell Using Bojarevics' Cell Stability Model

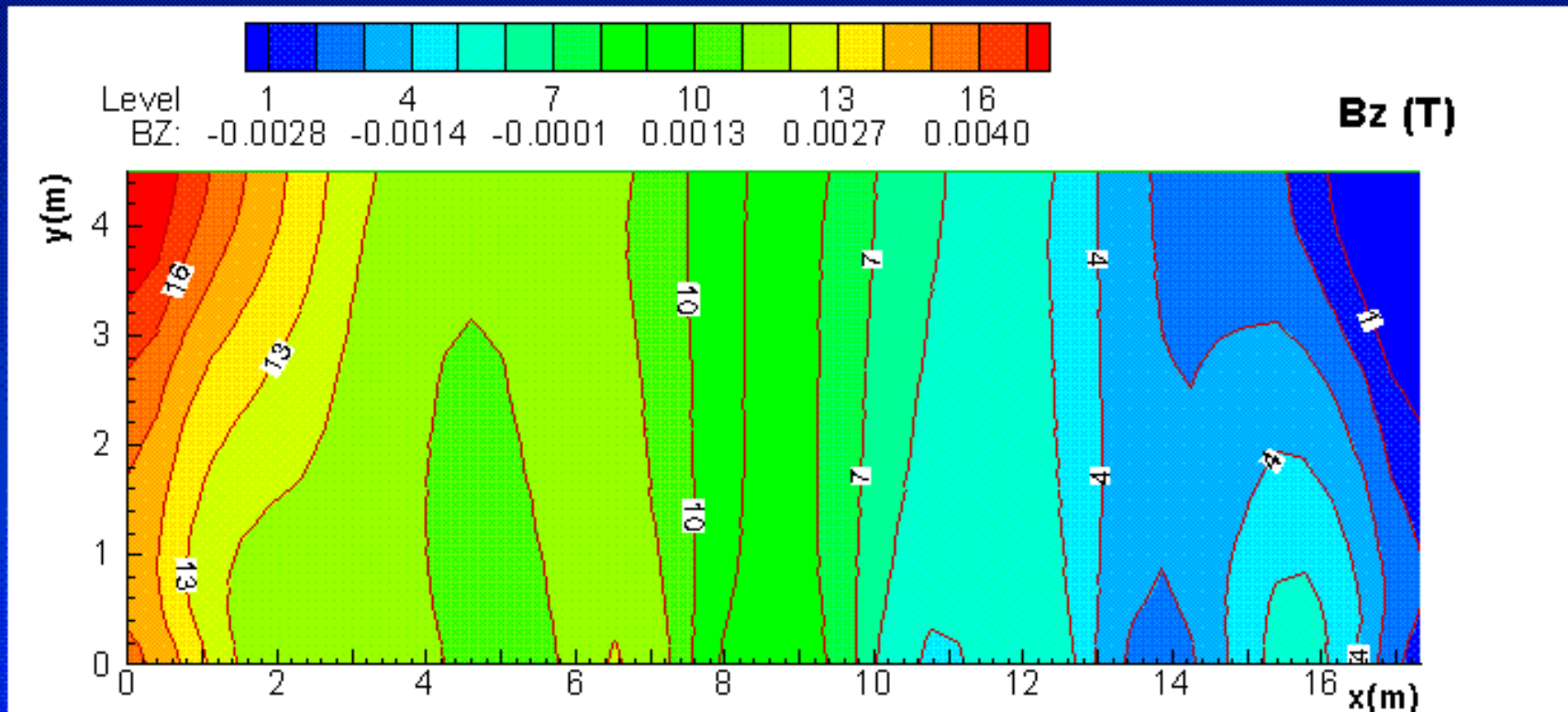


Including busbar design impact

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# MHD Design of a 500 kA cell Using Bojarevics' Cell Stability Model

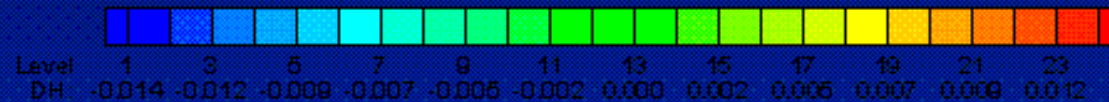


Magnetic field including shell shielding effect

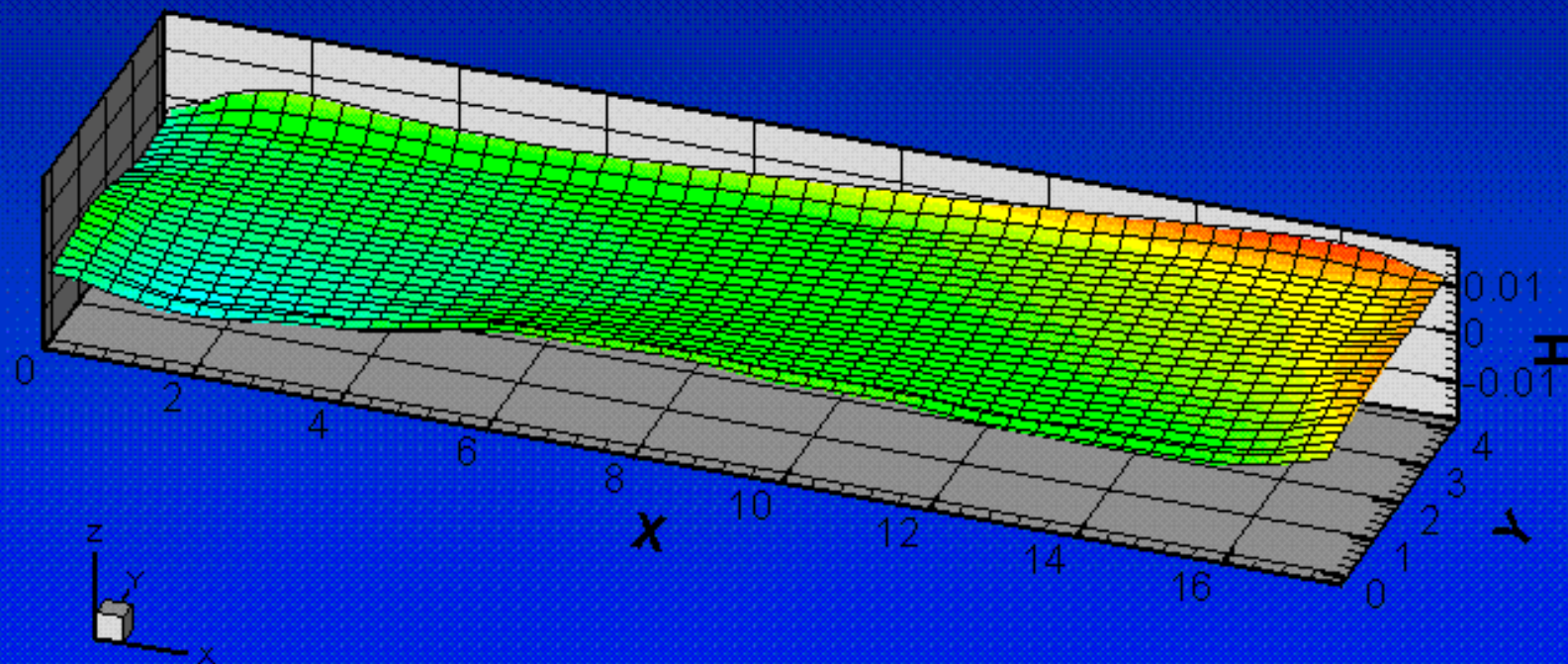
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# MHD Design of a 500 kA cell Using Bojarevics' Cell Stability Model

Interface, dH(m)

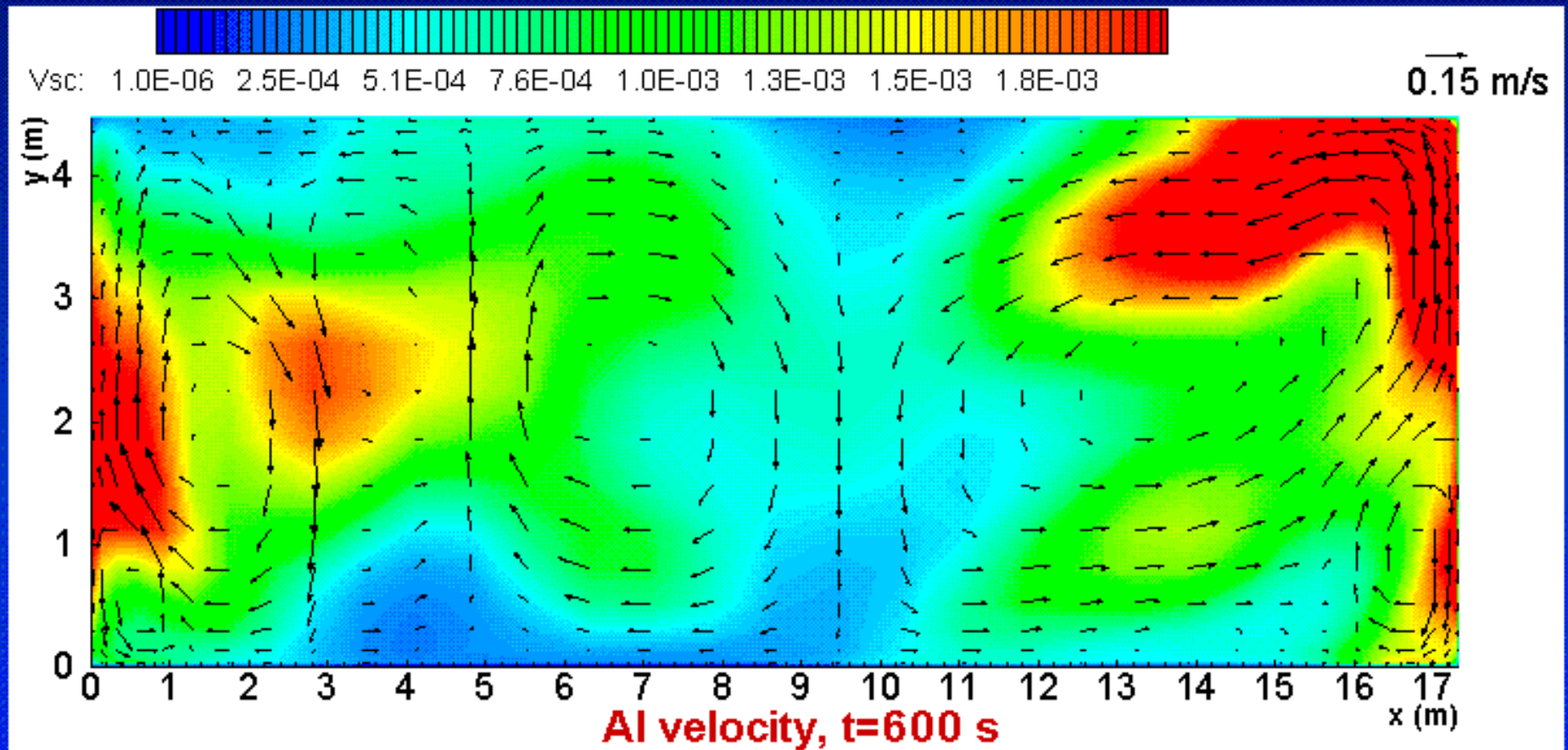


Assumed stationary interface



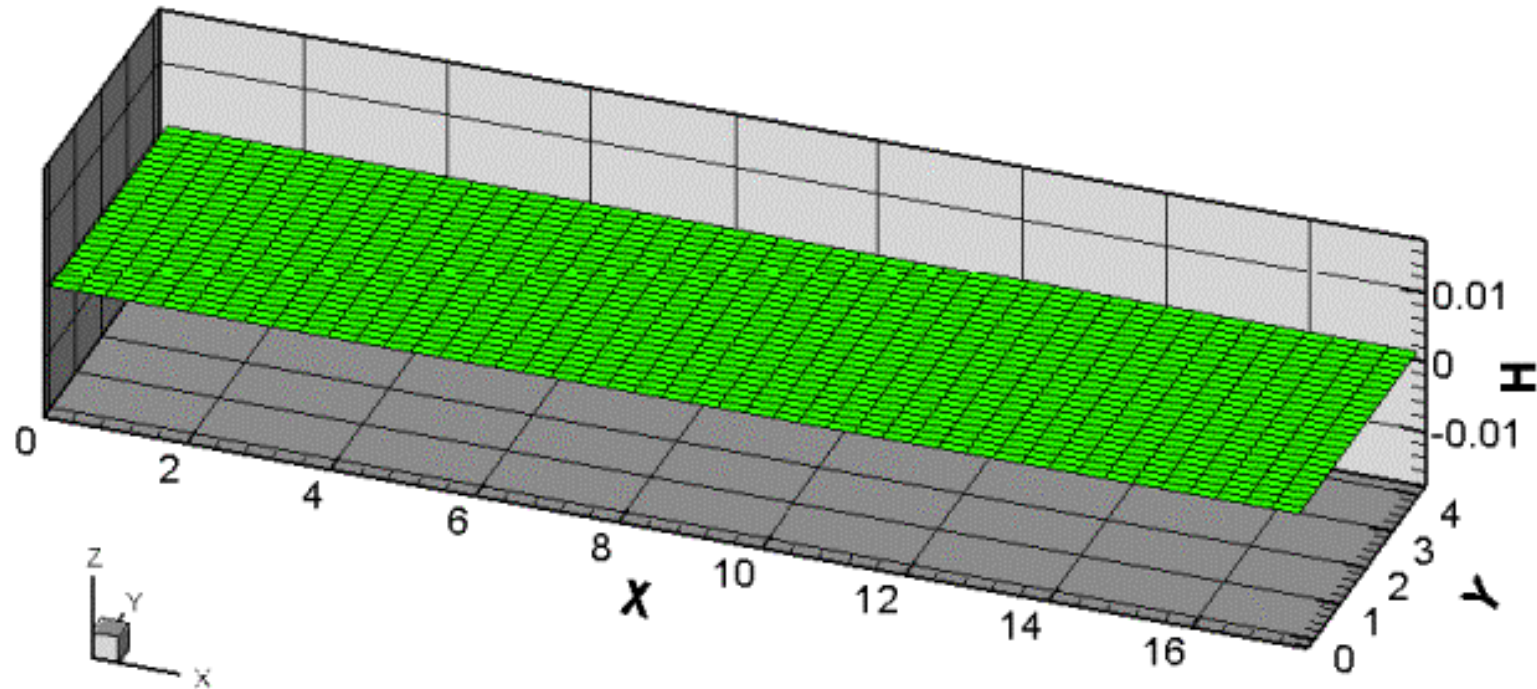
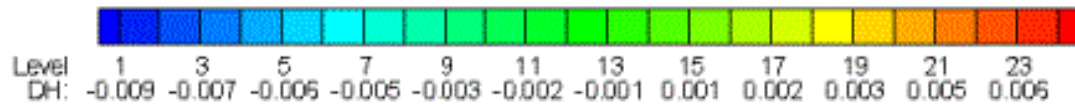
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# MHD Design of a 500 kA cell Using Bojarevics' Cell Stability Model



# MHD Design of a 500 kA cell Using Bojarevics' Cell Stability Model

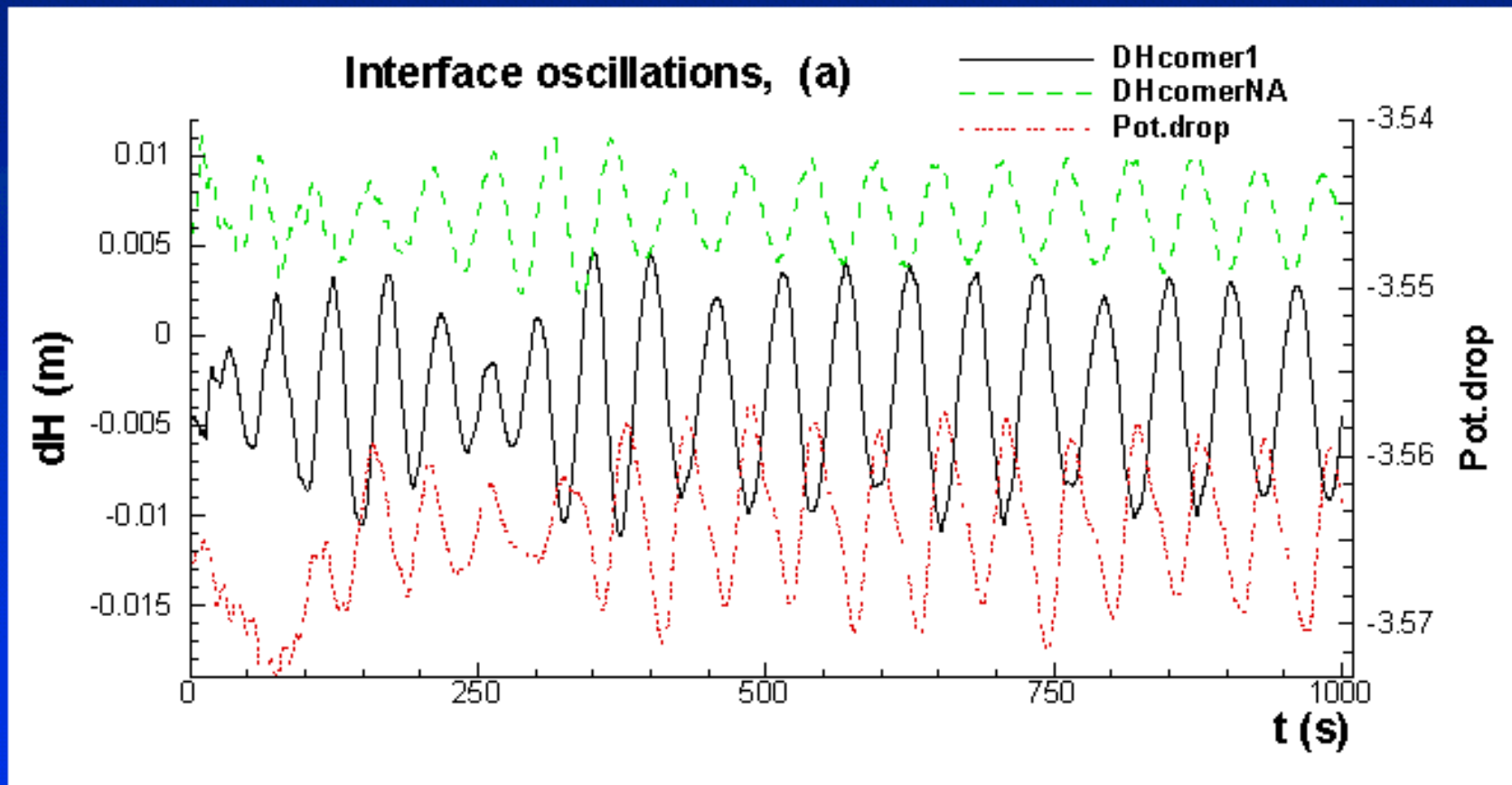
Interface, dH(m)



New500kA DH t= 0.0s

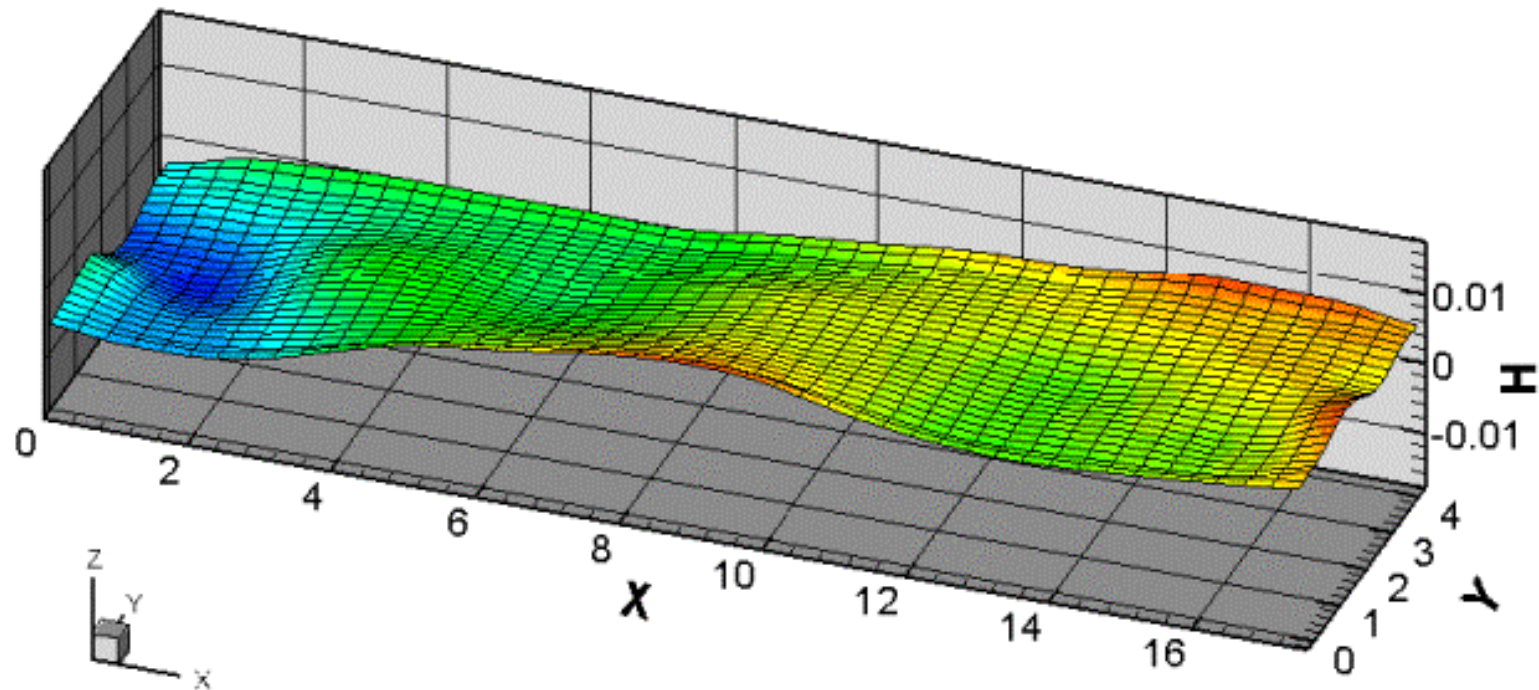
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# MHD Design of a 500 kA cell Using Bojarevics' Cell Stability Model



# MHD Design of a 500 kA cell Using Bojarevics' Cell Stability Model

Interface, dH(m)



New500kA DH t= 495.0s

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# Conclusions

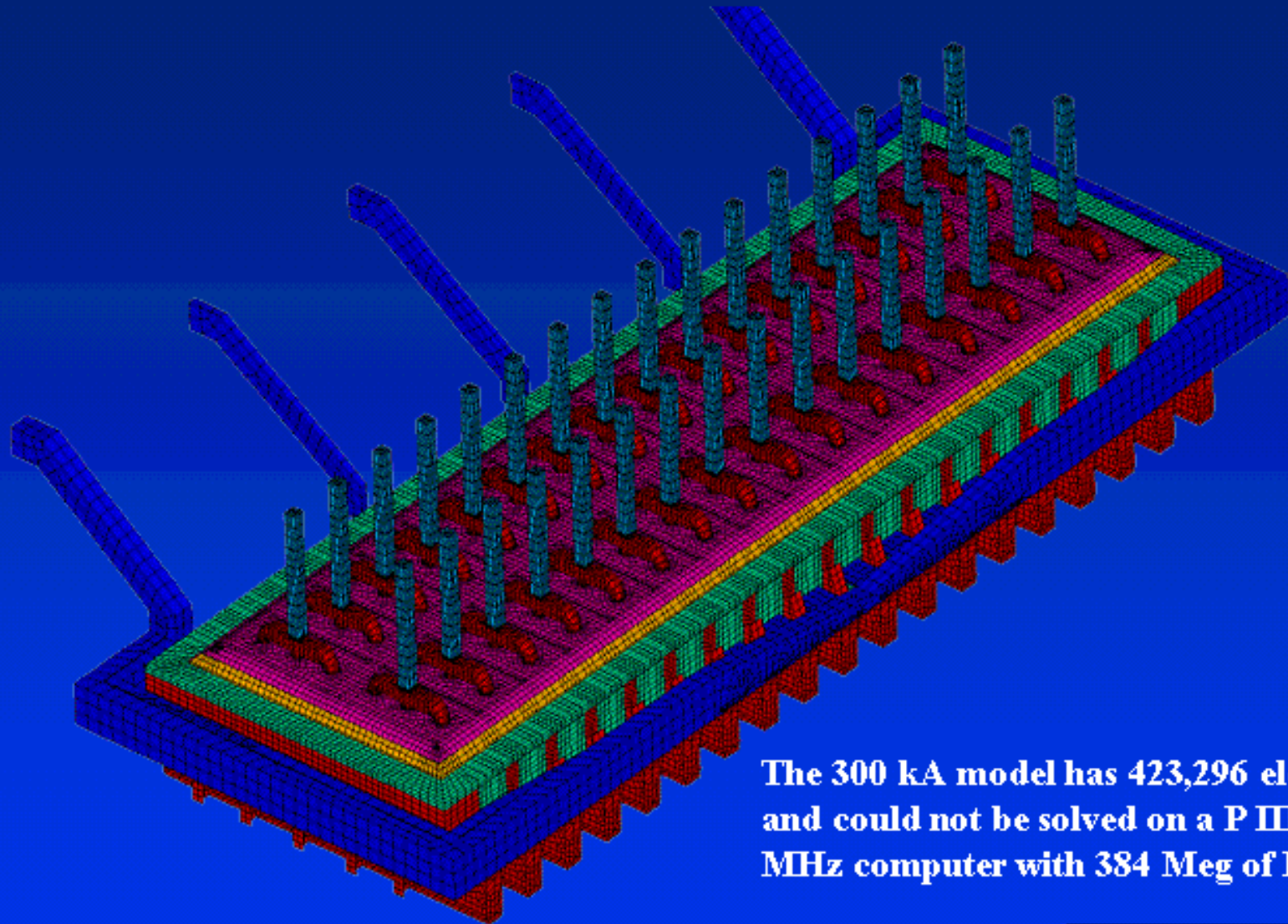
- **State of the art 3D thermo-electric and MHD models have been successfully used to produce a demonstration design of a 500 kA Al electrolysis cell.**
- **The aim of the present study was to start to investigate the impact of the interaction of both models on the local ledge profile prediction of the thermo-electric model and the current density field calculated by the MHD model and the resulting MHD cell stability prediction.**
- **As the initial step toward that goal, the metal pad current density field predicted by the two independent models have been compared . As it can be observed, the two metal pad current density field predictions are close but not identical.**

# Future Developments

- **The next step would be to use the MHD model fluid flow and especially turbulent viscosity solution to solve a 3D full cell plus external busbar thermo-electric model using local liquids/ledge heat transfer coefficients.**
- **The local ledge profile obtained from the 3D full cell thermo-electric model could in turn be used by the MHD model to compute its metal pad current density. Depending on the geometry of that local ledge profile, this could have a significant impact on the MHD model predicted cell stability.**
- **After, hopefully, no more than a few iterations between the two models, both solutions should converged producing a global (hopefully unique) weakly coupled thermo-electric and MHD solution.**



# Full Cell + External Busbar Thermo-Electric Model



The 300 kA model has 423,296 elements and could not be solved on a P III 800 MHz computer with 384 Meg of RAM !

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