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

Marc Dupuis GENISIM

Valdis Bojarevics *University of Greenwich, School of Computing and Mathematics*

Janis Freibergs *University of Latvia, Institute of Physics*

GENISIM

Plan of the Presentation

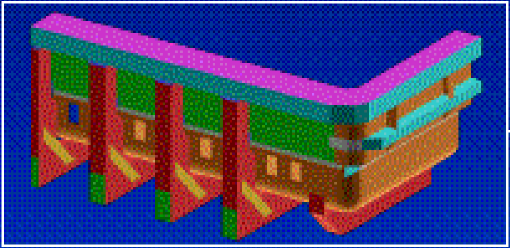
- Introduction
- Part 1: Dupuis' Thermo-Electric Models
  - Lump Parameters+ Cell Heat Balance Model
  - 3D Full Cell Side Slice Thermo-Electric Model
  - Complete Full Cell Quarter Thermo-Electric Model
- Part 2: Bojarevics' Cell Stability Model
- Conclusions
- Future Developments

GENISIM

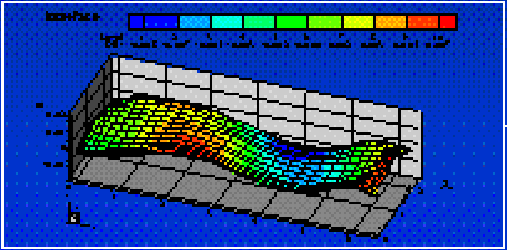
Modeling the Hall-Héroult Cell

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

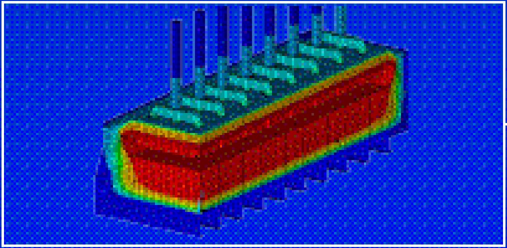
- Stress models which are generally associated with cell shell deformation and cathode heaving issues.



- Magneto-hydro-dynamic (MHD) models which are generally associated with the problem of cell stability.



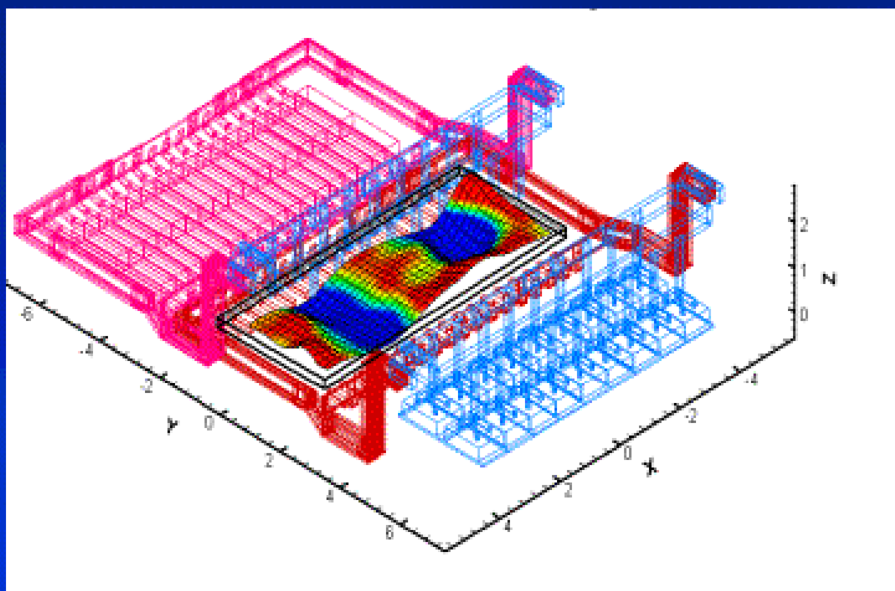
- Thermal-electric models which are generally associated with the problem of cell heat balance.



Cell Design

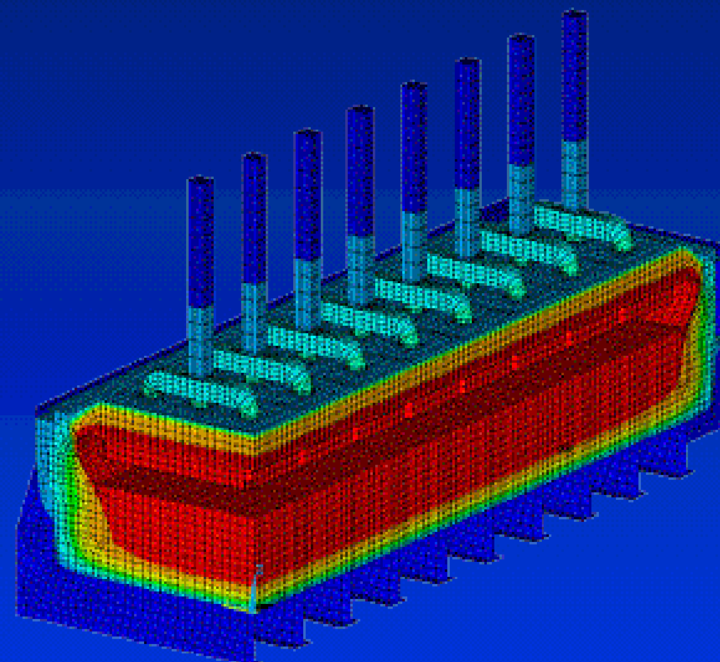
GENISIM

Modeling the Hall-Héroult Cell



MHD model:

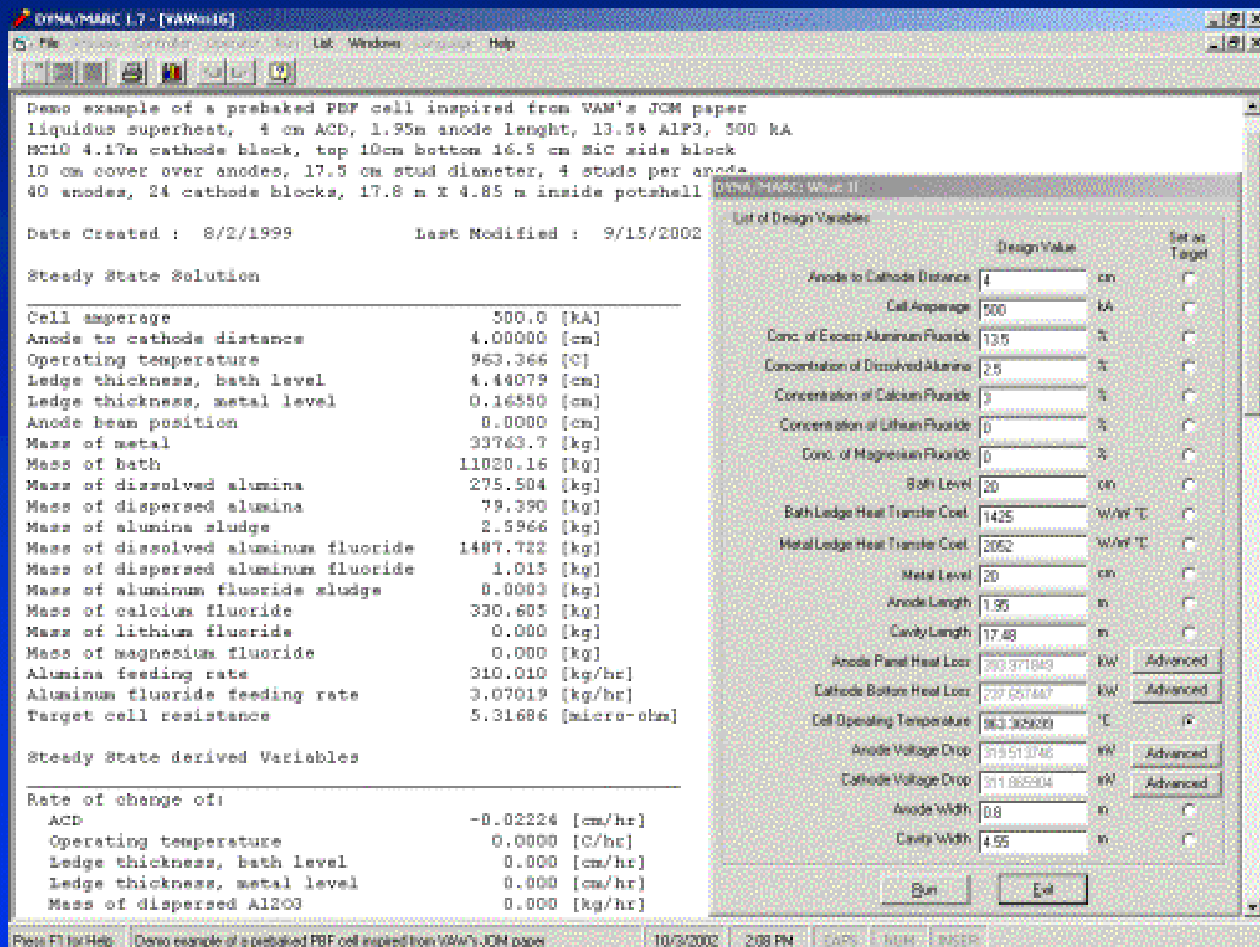
centered around the liquid zone



Thermo-electric model:

no need to include the liquid zone

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



GENISIM

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	**322 kA**	**330 kA**	330kA	330kA	330kA	**335 kA**	**350 kA**	**400 kA**
Nb. of anodes	32	32	32	32	32	32	32	32	**36**
Anode size	1.6 m X 0.8 m	1.6 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	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	**19 cm**	19 cm
Anode cover thickness	16 cm	16 cm	16 cm	16 cm	16 cm	16 cm	**10 cm**	10 cm	10 cm
Nb. of cathode blocks	18	18	18	18	18	18	18	18	**20**
Cathode block length	3.47 m	3.47 m	3.47 m	3.47 m	**3.67 m**	3.67 m	3.67 m	3.67 m	3.67 m
Type of cathode block	HC3	HC3	HC3	HC3	**HC10**	HC10	HC10	HC10	HC10
Type of side block	HC3	HC3	HC3	HC3	HC3	**SiC**	SiC	SiC	SiC
Side block thickness	15 cm +	15 cm +	15 cm +	15 cm +	15 cm +	**10 cm +**	10 cm +	10 cm +	10 cm +
ASD	35 cm	35 cm	**25 cm**	25 cm	25 cm	**30 cm**	30 cm	30 cm	30 cm
Inside 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	**16.1 X 4.35 m**
ACD	5 cm	**4 cm**	4 cm	4 cm	4 cm	4 cm	4 cm	4 cm	4 cm
Excess AlF_3	10.9 %	10.9 %	10.9 %	**13.5%**	13.5 %	13.5 %	13.5 %	13.5 %	13.5 %
Anode drop	306 mV	**325mV**	**328mV**	328 mV	328 mV	328 mV	**331mV**	**330mV**	335 mV
Cathode drop	290 mV	**311mV**	**319mV**	319 mV	**277mV**	277 mV	**281mV**	**293mV**	301 mV
Anode panel heat loss	239kW	**244 kW**	**247 kW**	247kW	**247 kW**	**250 kW**	**275 kW**	**284 kW**	311kW
Cathode bottom heat loss	166kW	**167 kW**	**168 kW**	168kW	**171 kW**	171kW	**172 kW**	**173 kW**	193kW
Operating temperature	973.3 °C	973.3 °C	973.3 °C	**960.8 °C**	**960.3 °C**	**960.2 °C**	**960.0 °C**	**961.5 °C**	**962.7 °C**
Liquidus superheat	6.8 °C	6.8 °C	6.8 °C	**7.2 °C**	**6.6 °C**	**6.5 °C**	**6.3 °C**	**7.8 °C**	**9.0 °C**
Bath ledge thickness	7.61 cm	**7.75 cm**	**7.71 cm**	**6.85 cm**	**7.81 cm**	**9.02 cm**	**9.34 cm**	**6.69 cm**	**5.11 cm**
Metal ledge thickness	2.79 cm	**2.93 cm**	**2.88 cm**	**2.03 cm**	**2.98 cm**	**4.75 cm**	**5.07 cm**	**2.42 cm**	**0.83 cm**
Current efficiency	94.0 %	**94.4%**	**94.2%**	**95.9%**	**95.9%**	95.9 %	**96.0%**	96.0 %	96.0 %
Internal heat	628kW	**633 kW**	**637 kW**	**647 kW**	**633 kW**	633kW	**652 kW**	**712 kW**	**825 kW**
Energy consumption	13.75 kWh/kg	**13.32 kWh/kg**	**13.20 kWh/kg**	**13.14 kWh/kg**	**13.01 kWh/kg**	**13.00 kWh/kg**	**13.10 kWh/kg**	**13.37 kWh/kg**	**13.49 kWh/kg**

GENISIM

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	DynaMarc 1.7	DynaMarc 1.7	DynaMarc 1.7	DynaMarc 1.7	DynaMarc 1.7
Amperage	400 kA	**440 kA**	**480 kA**	**490 kA**	**500 kA**
Nb. of anodes	36	**40**	40	40	40
Anode size	1.7 m X 0.8 m	1.7 m X 0.8 m	**1.95 m X 0.8 m**	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	**4 per anode**	4 per anode
Anode stud diameter	19 cm	19 cm	19 cm	**17.5 cm**	17.5 cm
Anode cover thickness	10 cm	10 cm	10 cm	10 cm	10 cm
Nb. of cathode blocks	20	**22**	22	22	**24**
Cathode block length	3.67 m	3.67 m	**4.17 m**	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	**17.8 X 4.35 m**	**17.8 X 4.85 m**	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_3	13.5 %	13.5 %	13.5 %	13.5 %	13.5 %
Anode drop	335 mV	**332 mV**	**347 mV**	**314 mV**	**320 mV**
Cathode drop	301 mV	**331 mV**	**324 mV**	**331 mV**	**312 mV**
Anode panel heat loss	311 kW	**335 kW**	**367 kW**	**391 kW**	**394 kW**
Cathode bottom heat loss	193 kW	**202 kW**	**231 kW**	**231 kW**	**238 kW**
Operating temperature	962.7 °C	**963.4 °C**	**962.8 °C**	962.8 °C	**963.4 °C**
Liquidus superheat	9.0 °C	**9.7 °C**	**9.1 °C**	9.1 °C	**9.7 °C**
Bath ledge thickness	5.11 cm	**4.43 cm**	**4.97 cm**	**4.99 cm**	**4.44 cm**
Metal ledge thickness	0.83 cm	**0.15 cm**	**0.70 cm**	**0.71 cm**	**0.17 cm**
Current efficiency	96.0 %	**95.9 %**	**95.8 %**	**95.9 %**	95.9 %
Internal heat	825 kW	**916 kW**	**964 kW**	**988 kW**	**1019 kW**
Energy consumption	13.49 kWh/kg	**13.53 kWh/kg**	**13.31 kWh/kg**	**13.33 kWh/kg**	**13.39 kWh/kg**

GENISIM

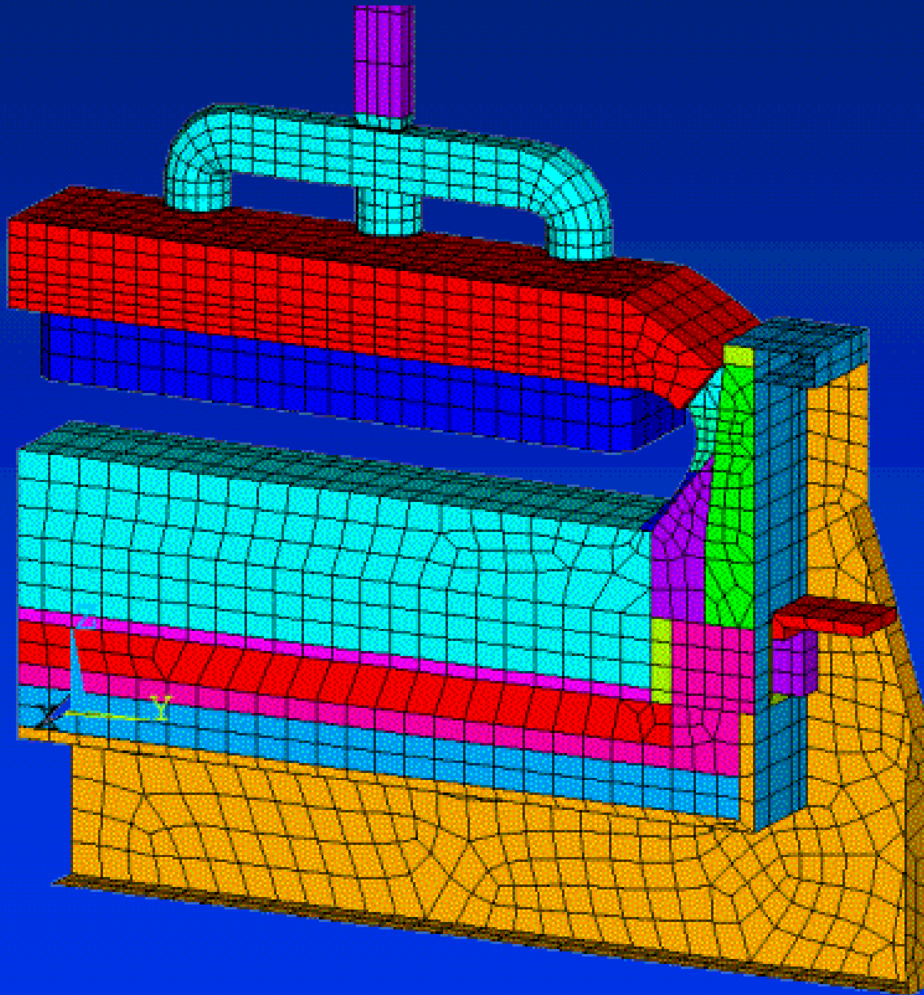
Thermo-Electric Design of a 500 kA cell Using a 3D Full Cell Side Slice Thermo-Electric Model

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^2
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

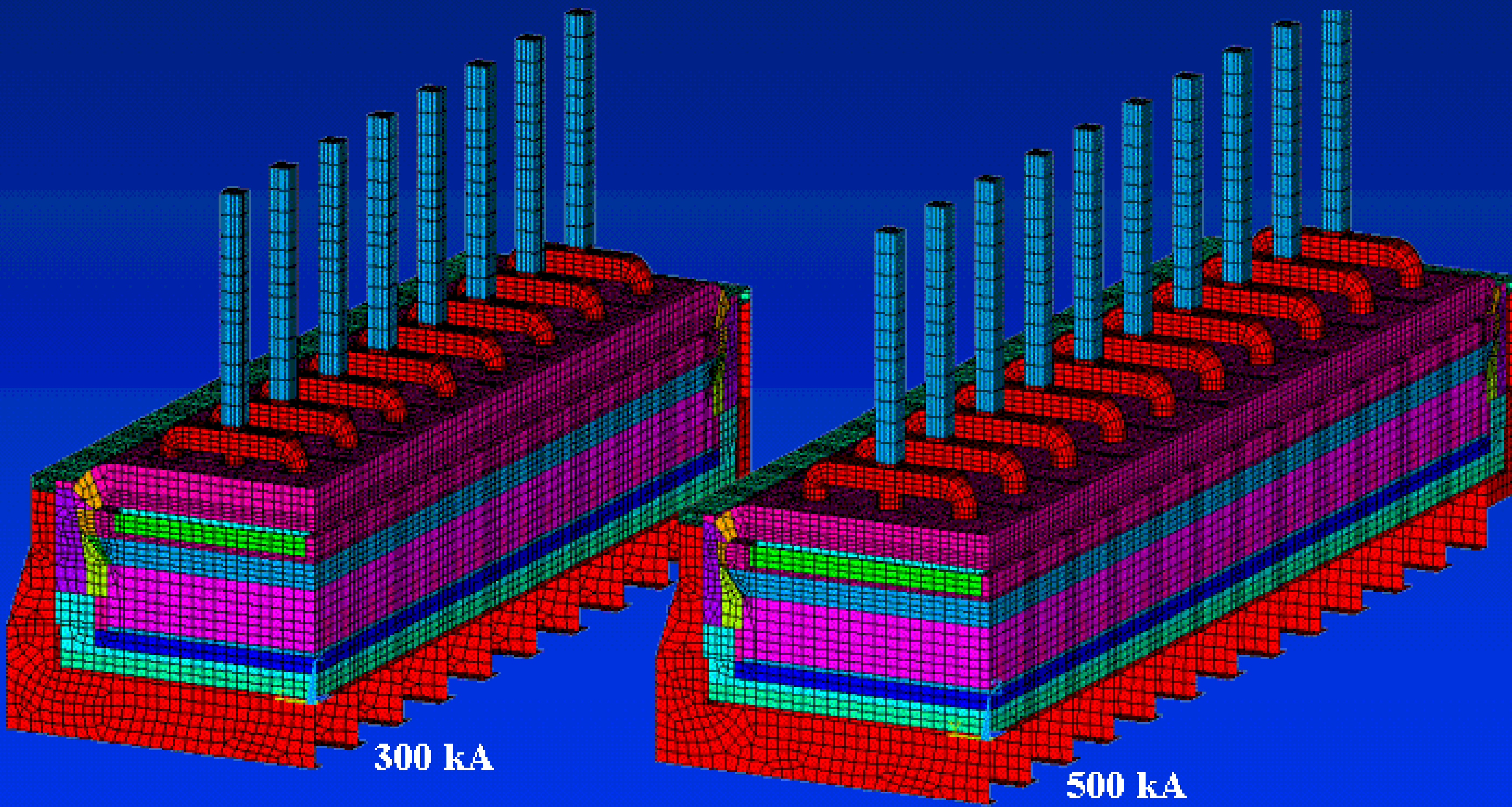
3D Full Cell Side Slice T-E Model's Key Results

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



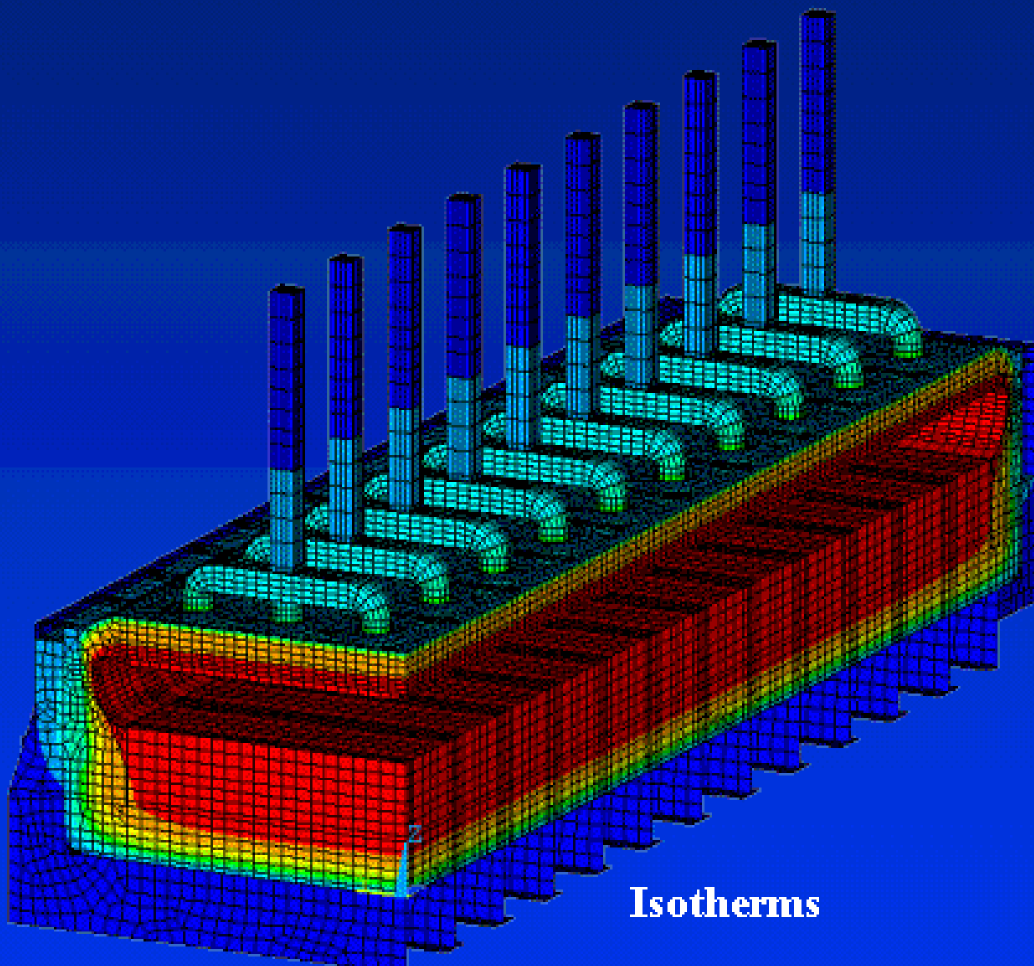
GENISIM

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

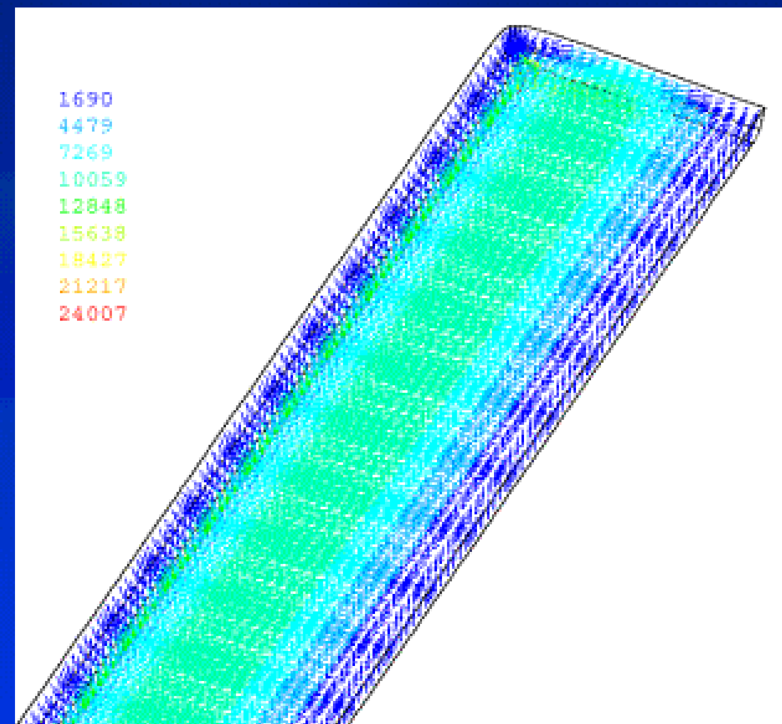


GENISIM

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



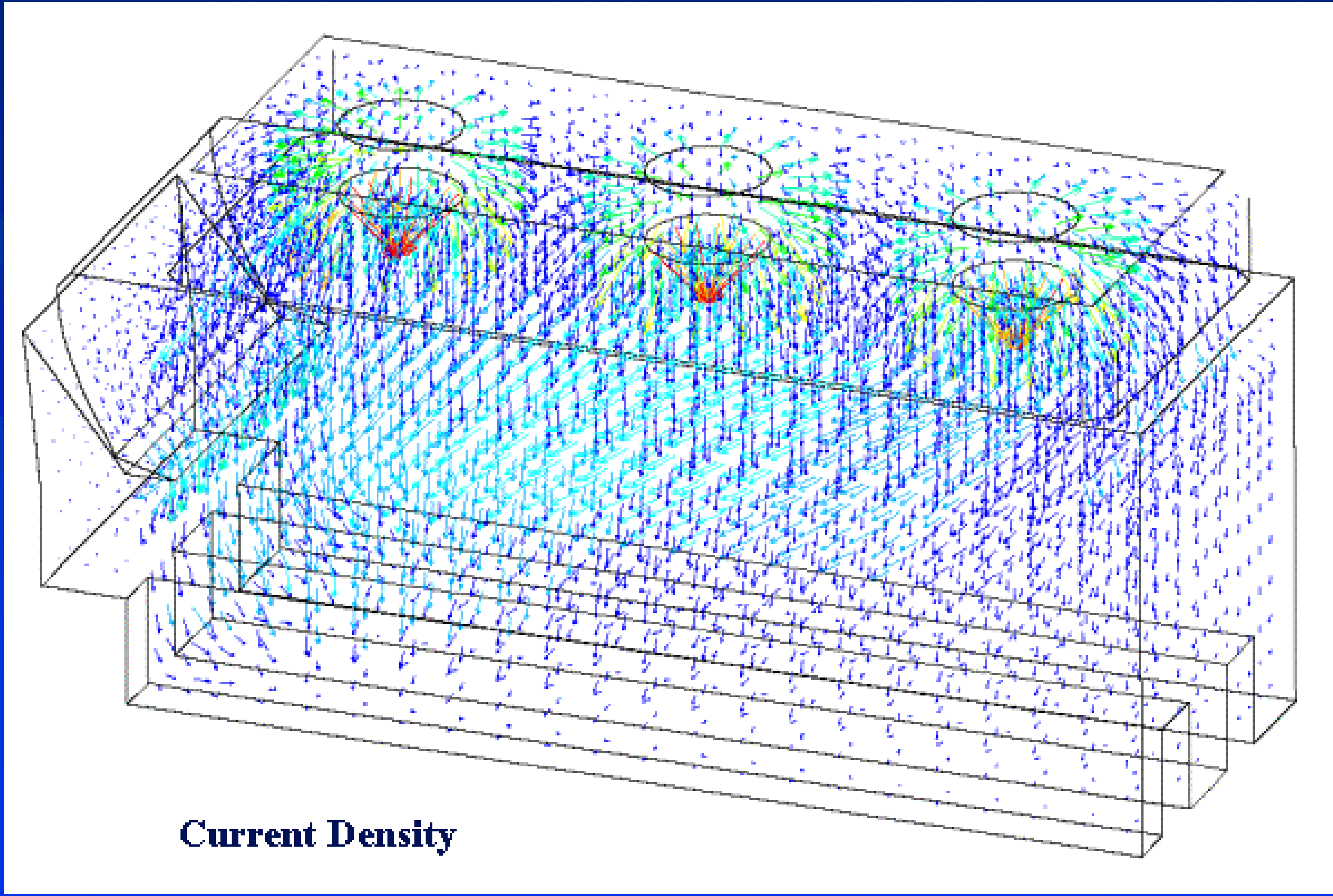
Isotherms



Current Density in metal pad

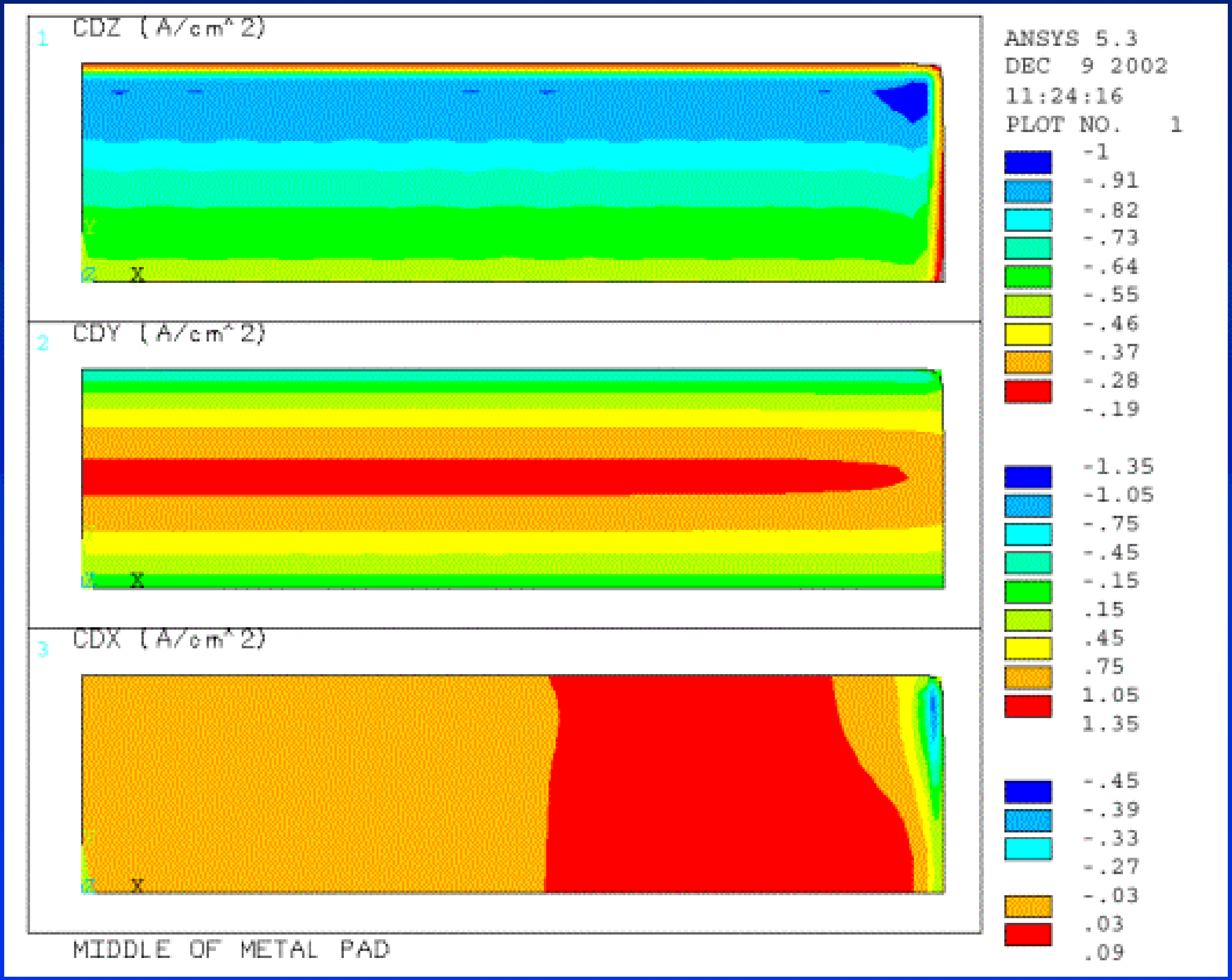
GENISIM

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



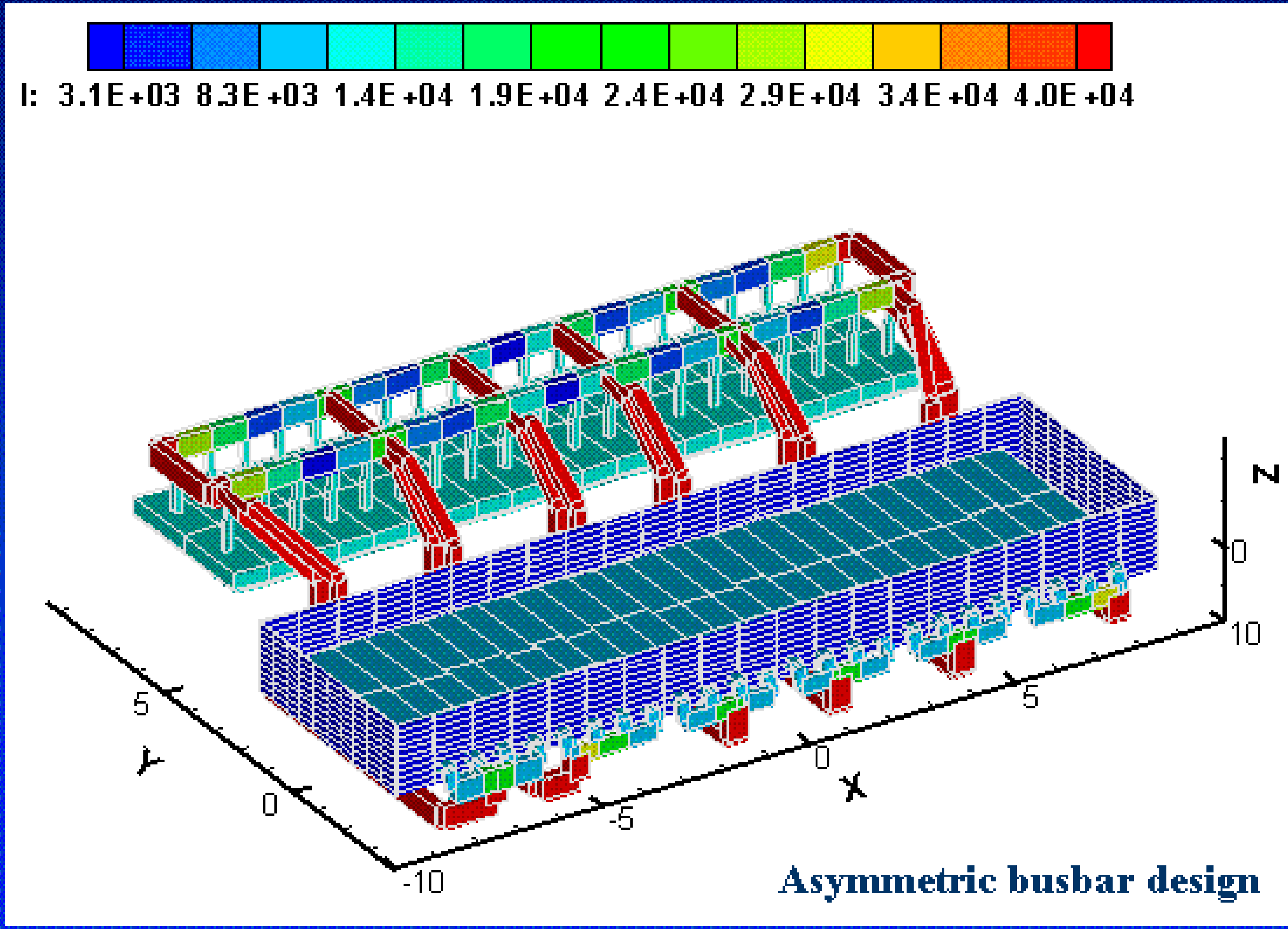
GENISIM

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



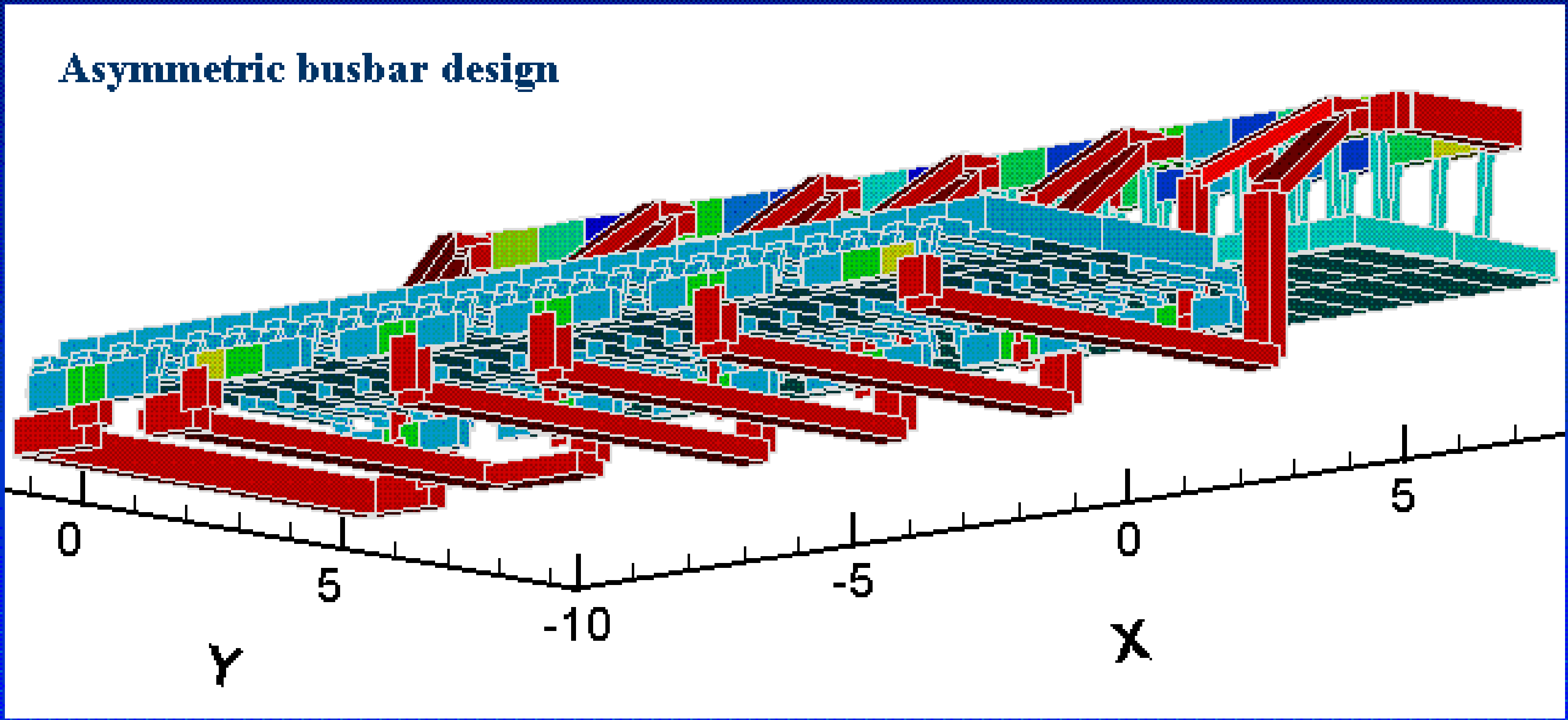
GENISIM

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



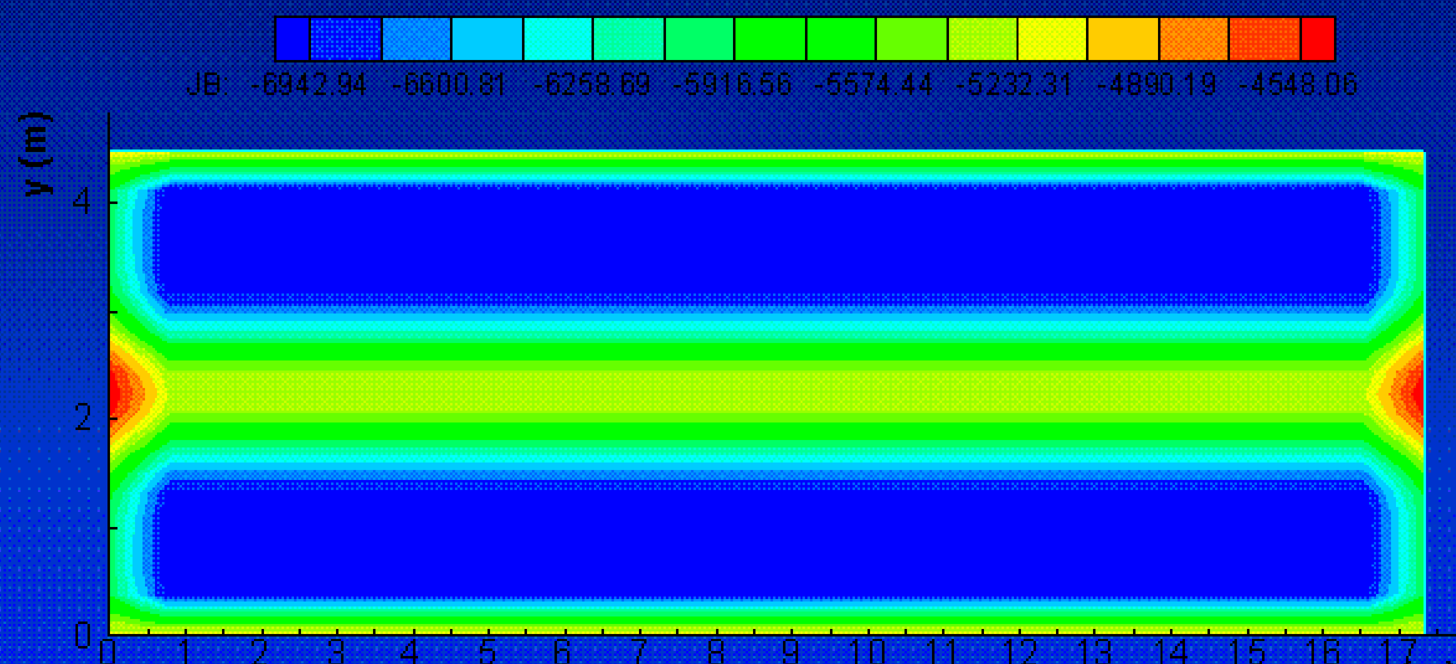
GENISIM

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



GENISIM

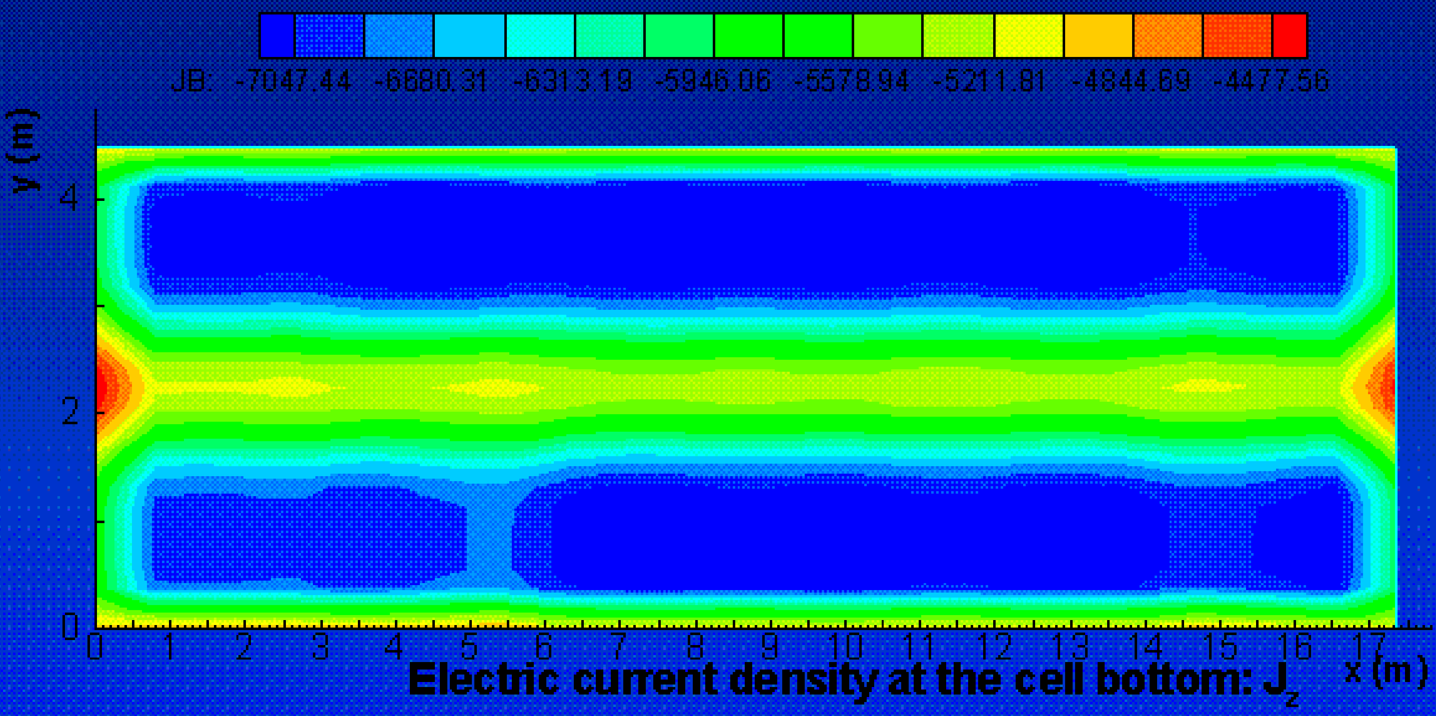
MHD Design of a 500 kA cell Using Bojarevics' Cell Stability Model



Electric current density at the cell bottom: J_z

Uniform current pickup

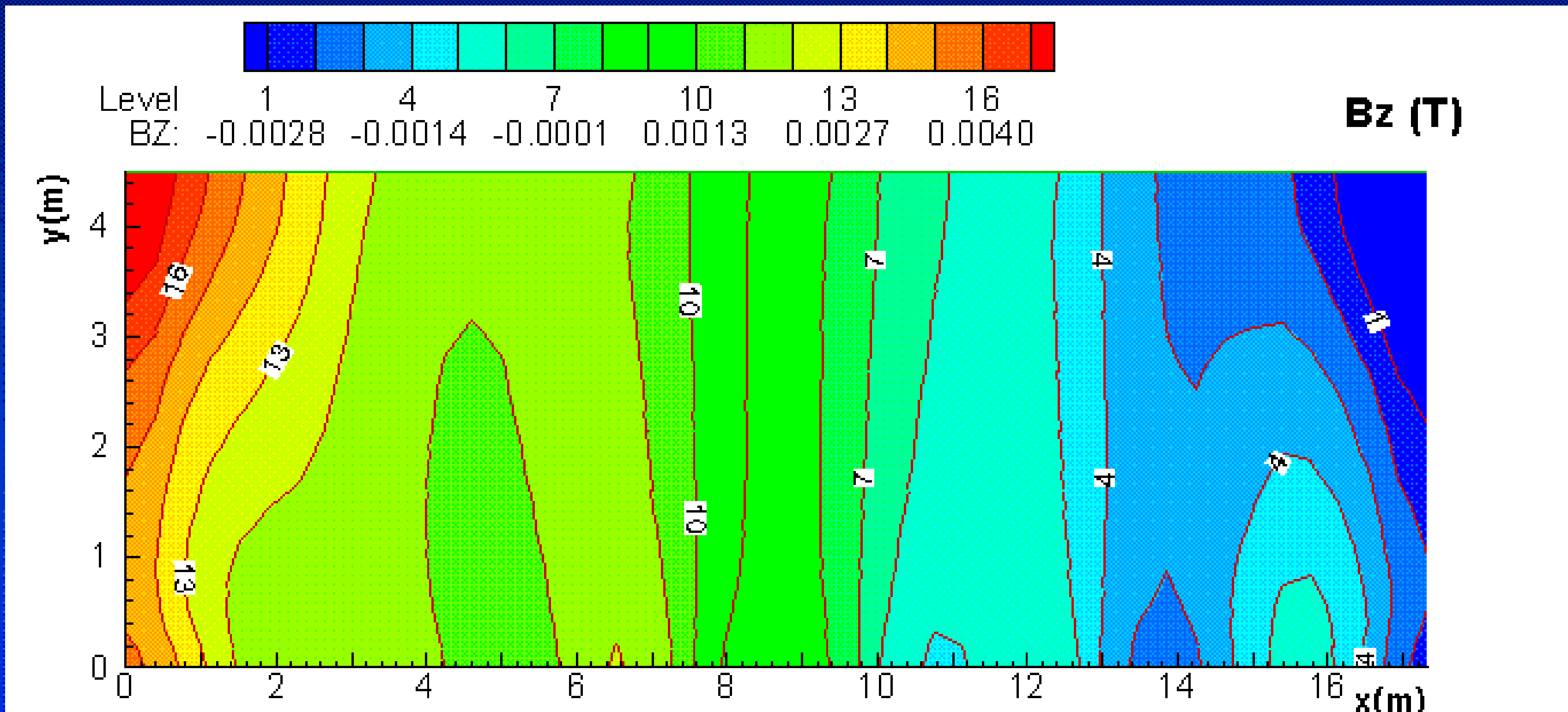
MHD Design of a 500 kA cell Using Bojarevics' Cell Stability Model



Including busbar design impact

GENISIM

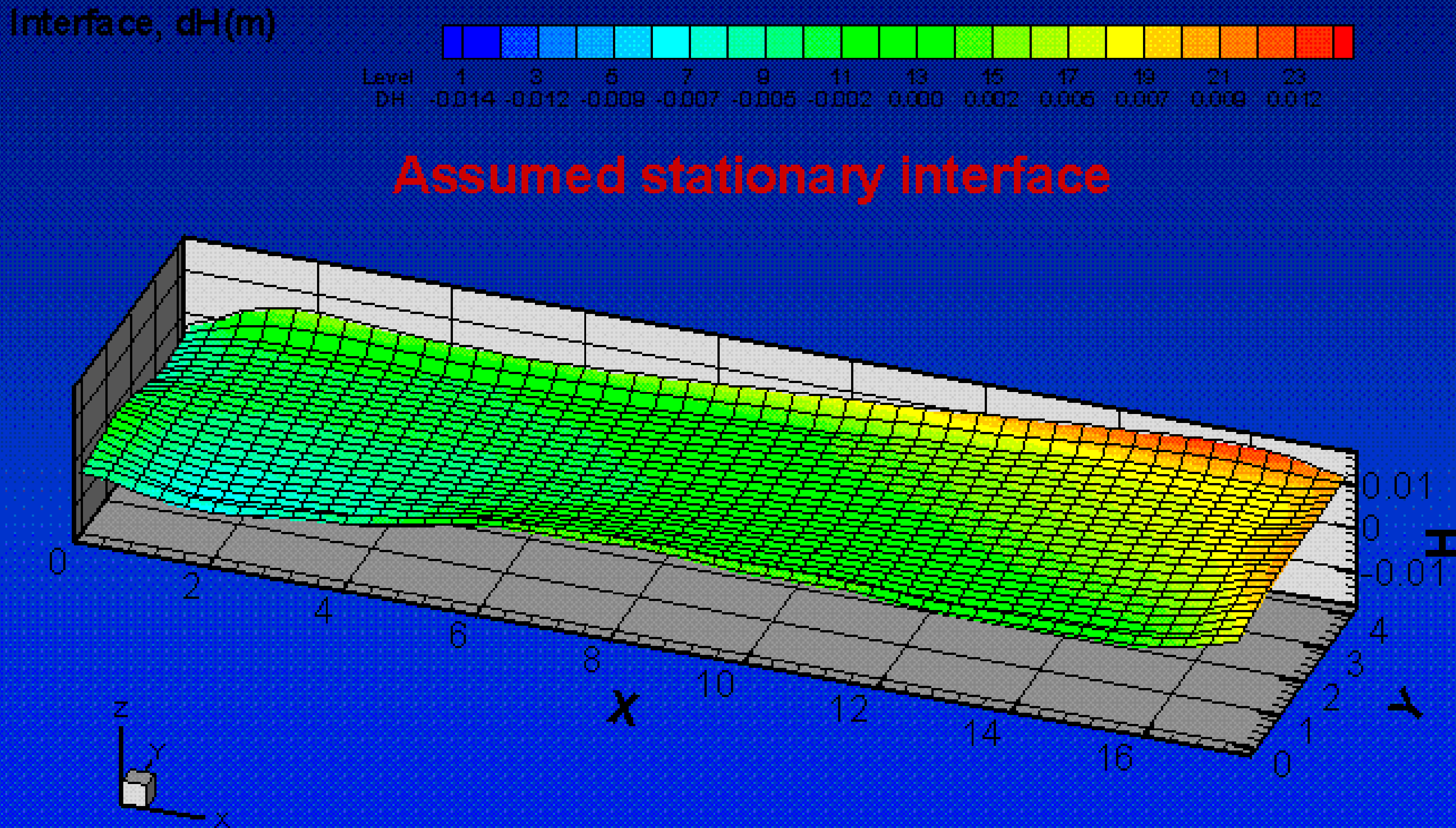
MHD Design of a 500 kA cell Using Bojarevics' Cell Stability Model



Magnetic field including shell shielding effect

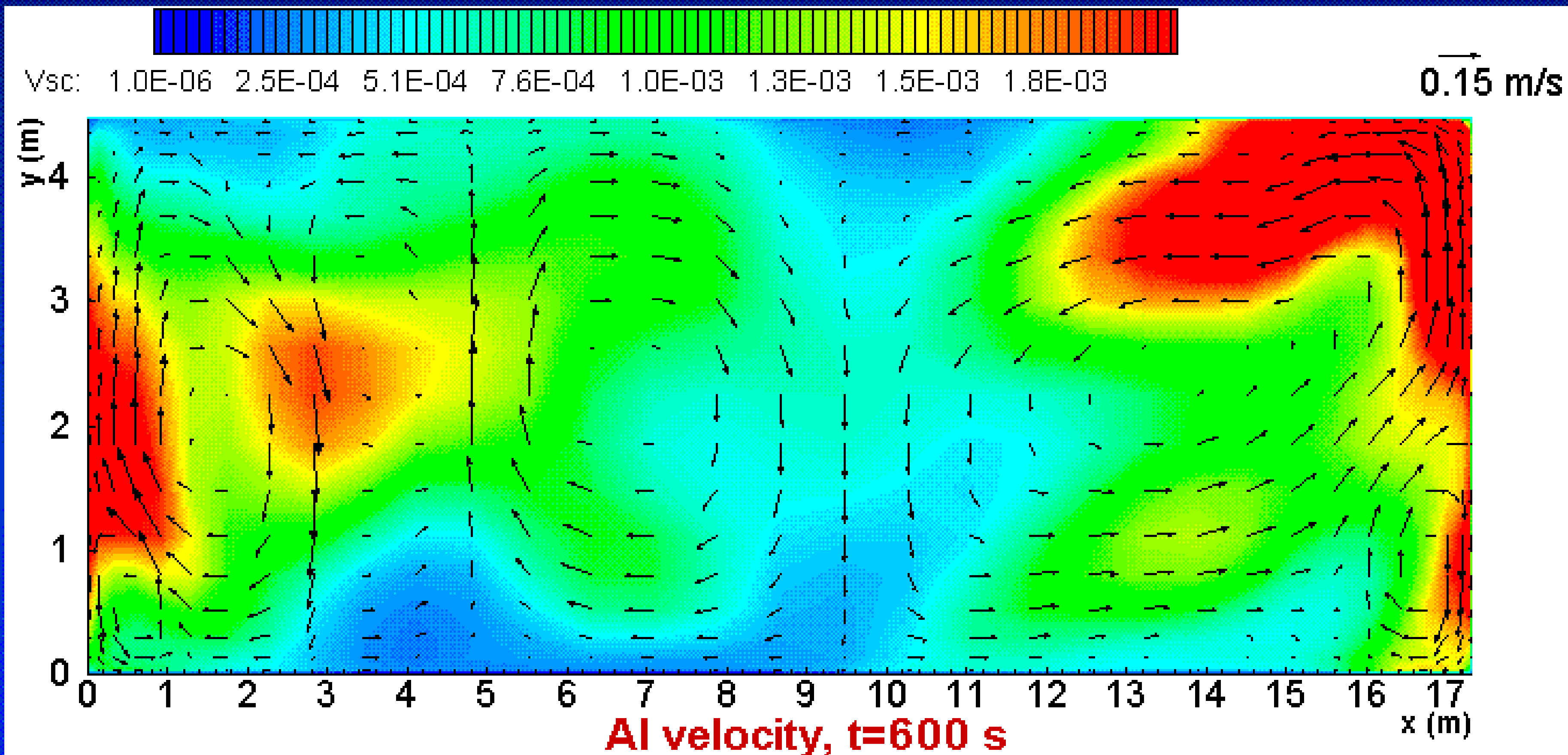
GENISIM

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



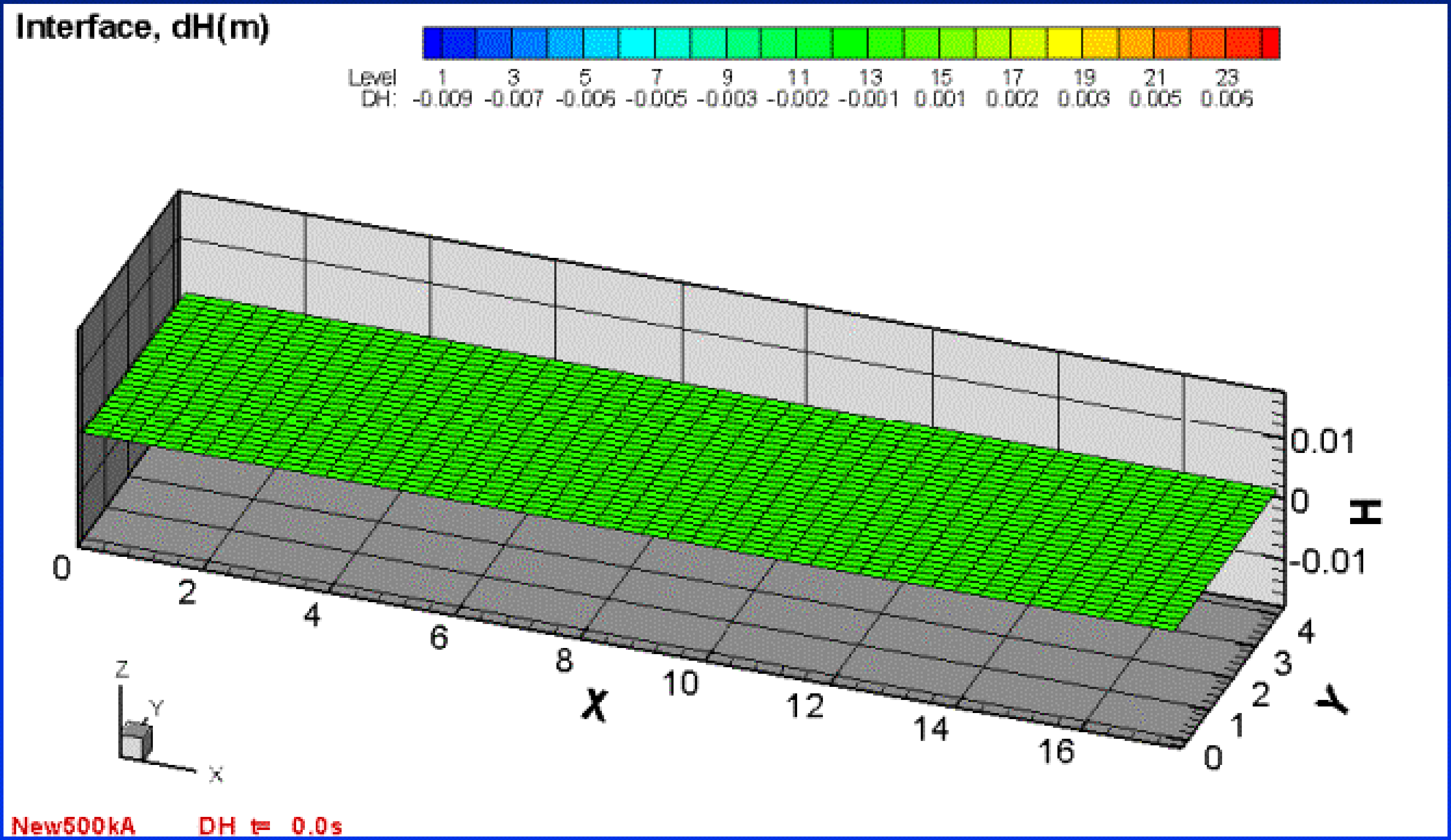
GENISIM

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



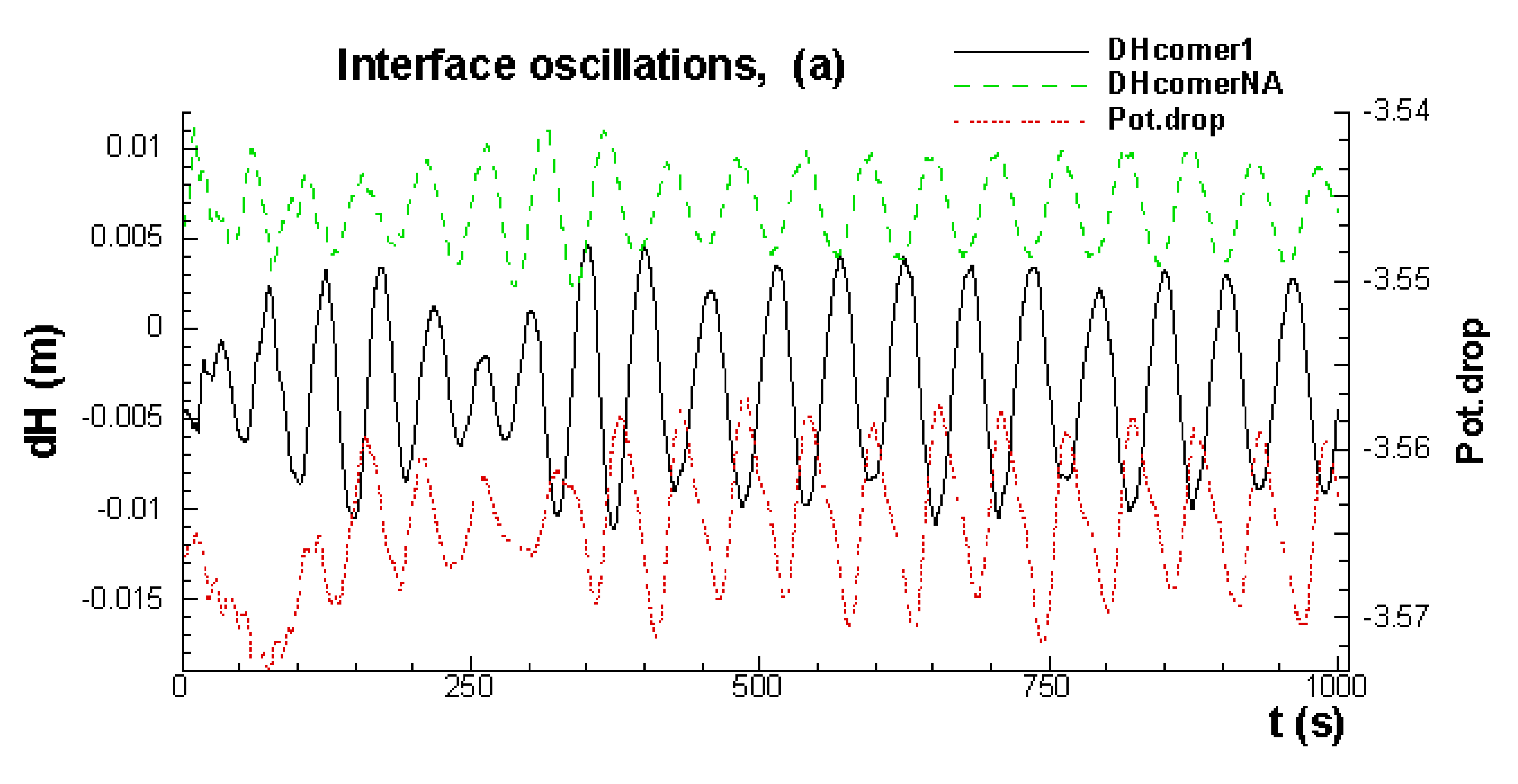
GENISIM

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

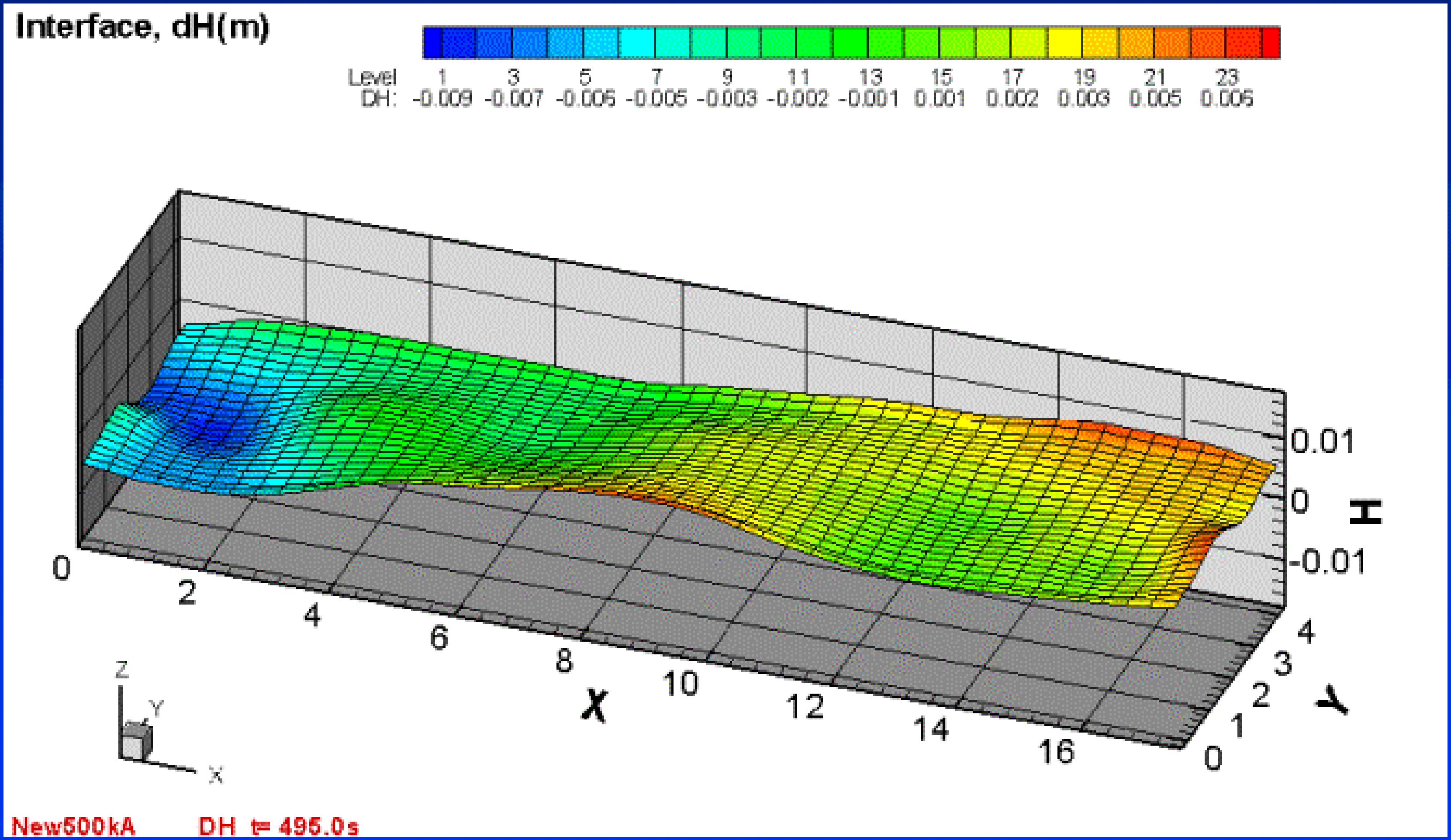


GENISIM

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



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



GENISIM

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.

GENISIM

Future Developments

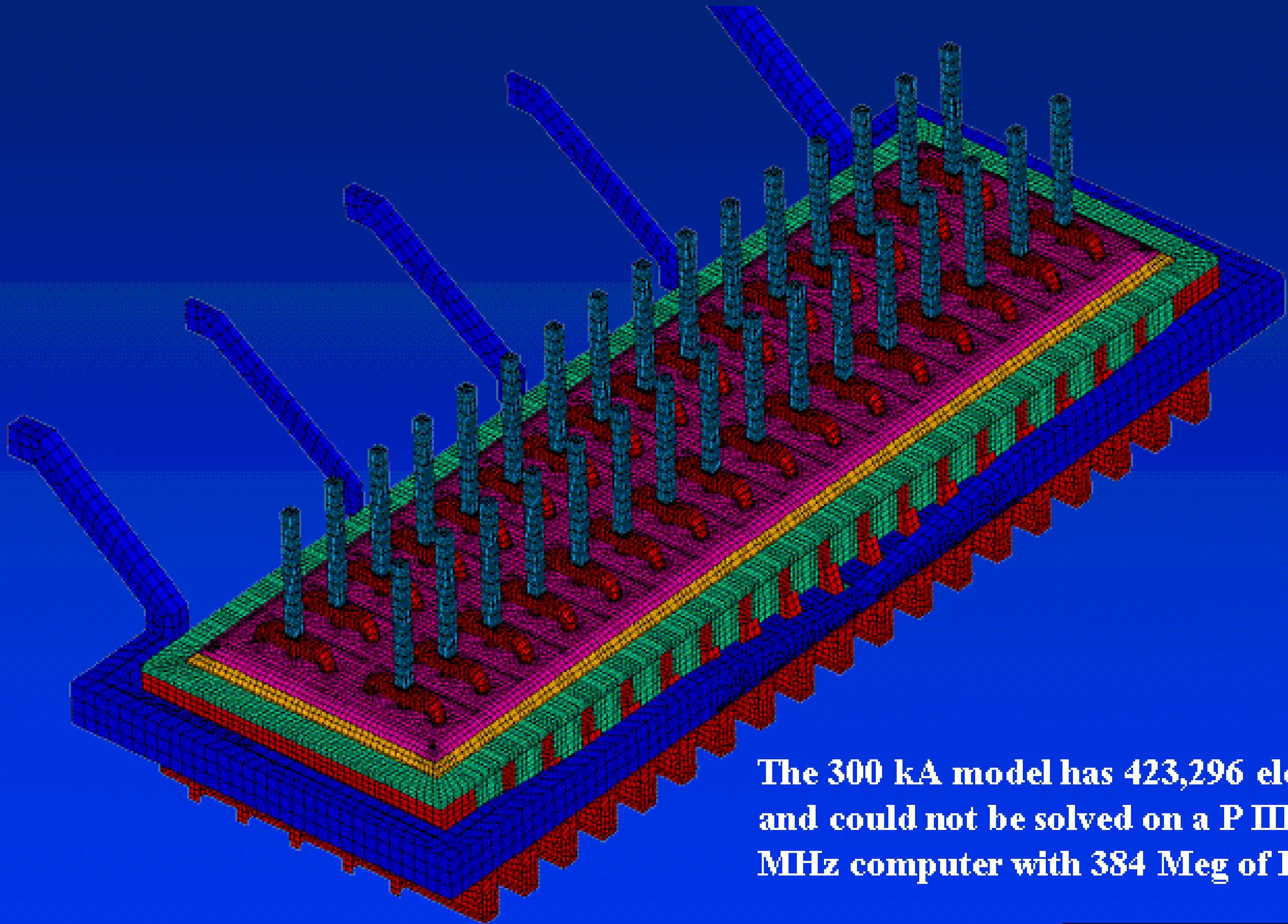
- The next step would be to use the MHD model fluid flow and especially turbulent viscosity solution to solve a 3D full cell plus external busbar thermo-electric model using local liquids/ledge heat transfer coefficients.

- 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.

GENISIM

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 !