LOW ENERGY CONSUMPTION CELL DESIGNS INVOLVING COPPER INSERTS AND AN INNOVATIVE BUSBAR NETWORK LAYOUT

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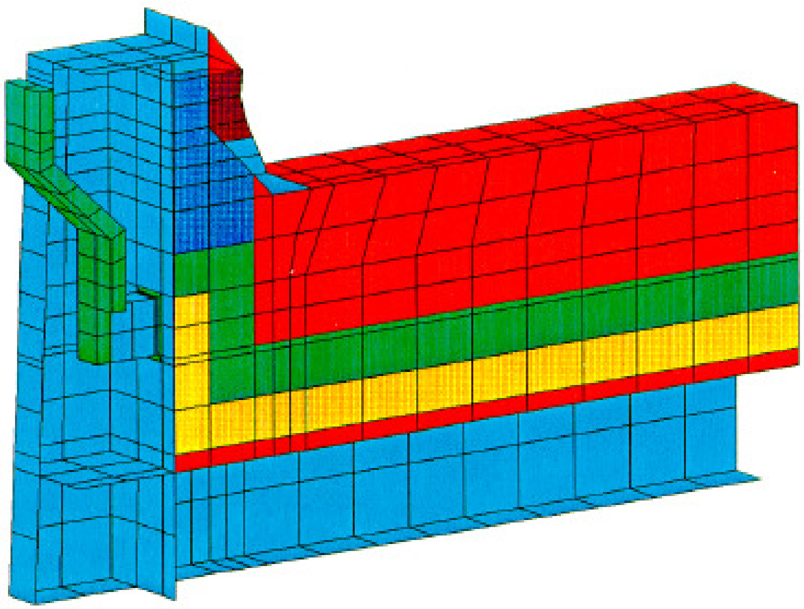
GENISIM

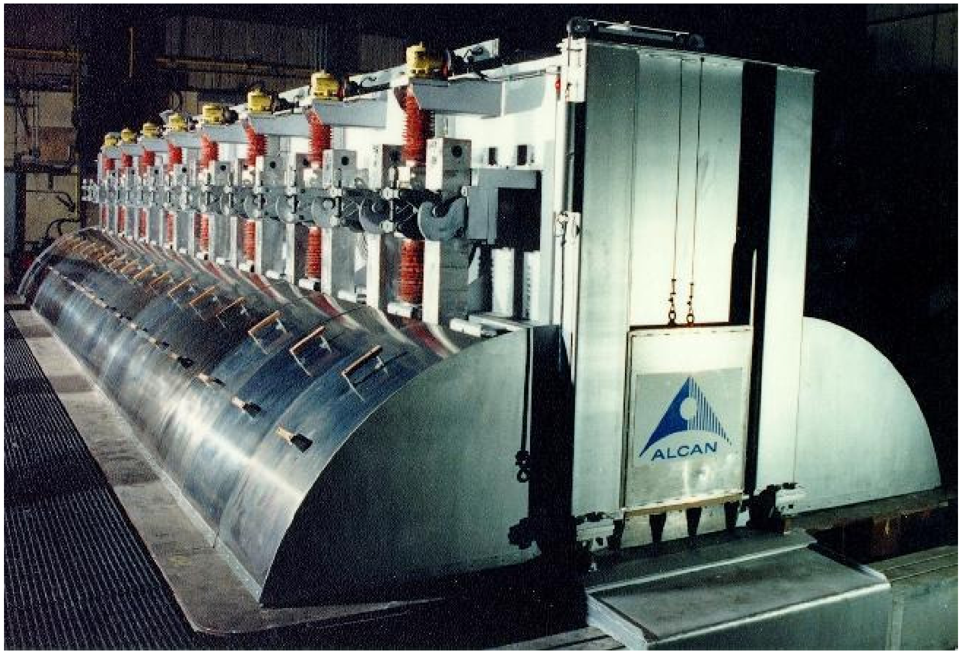
Plan of the Presentation

- Introduction: previous retrofit studies
- New retrofit study aiming at minimizing cell energy consumption even further
  - Cathode design with copper collector bars
  - External compensation current (ECC) busbar network design
  - Anode design with innovative stub hole conception
  - Calculation of the resulting cell energy consumption
- Conclusions

Introduction

- **In 1988, the author designed the cathode of the Alcan A310 prototype cell, the first cell to operate above 300 kA in 1989.**

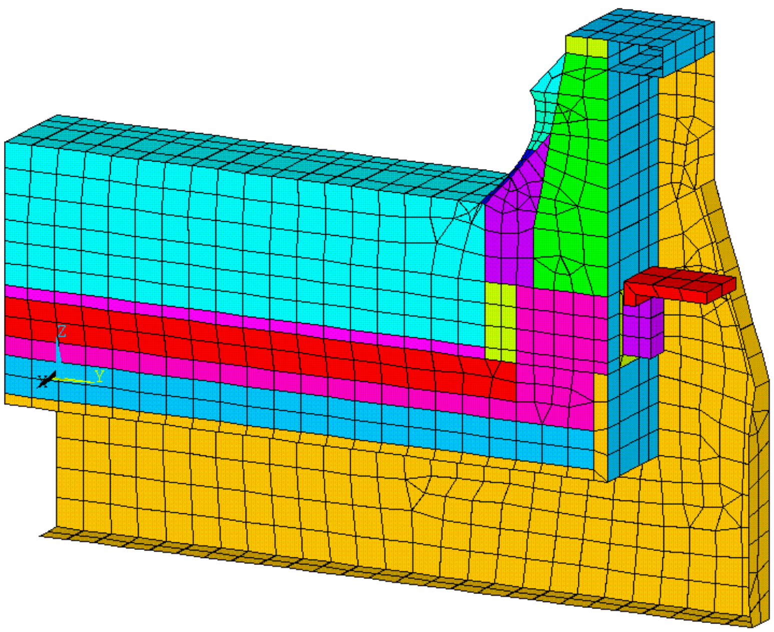


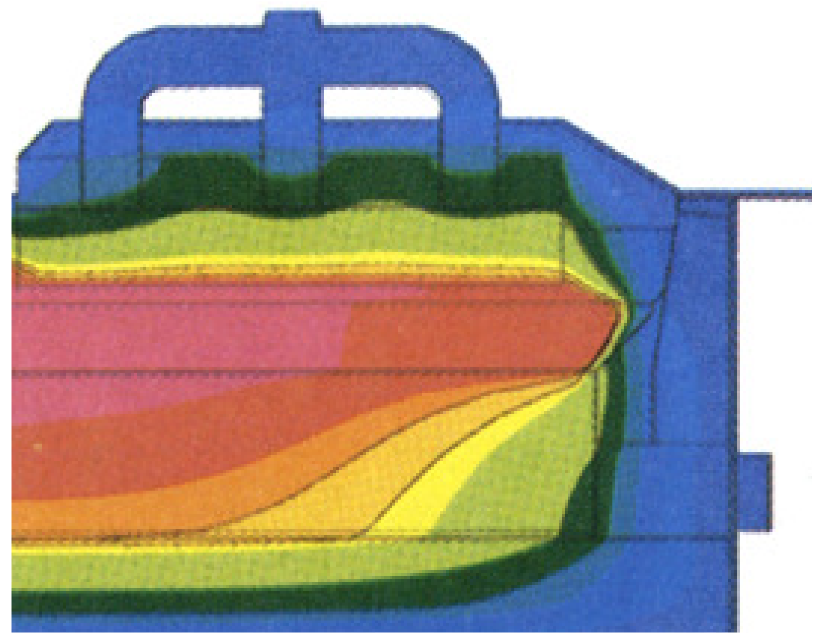


Ref: M. Dupuis and I. Tabsh, "Thermo Electric Coupled Field Analysis of Aluminum Reduction Cells Using the ANSYS Parametric Design Language", Proceeding of the ANSYS® Fifth International Conference, volume 3, 1991, pp. 17.80 17.92

Introduction

- **A few years later, the author developed a similar demonstration model strongly inspired by the VAW CA300 cell design presented in JOM in 1994.**





Ref: M. Dupuis, "Les modèles thermiques", 2e Symposium québécois sur le procédé d'électrolyse de l'aluminium, CQRDA, 1997.

Introduction

- The A310 and the CA300 cells were designed at about the same time and operated at about the same amperage.
- Both designers clearly respected similar design guidelines for the choice of the type of cathode blocks and side blocks, the thickness of that side block, the size of the anode to side wall distance (ASD), the location of the anode shadow, etc.
- That 300 kA demonstration model typical of the early 1990's state of the art in cell design became the base case for two retrofit studies.

Summary of the first retrofit study

	Base case		
Amperage	300 kA	265 kA	350 kA
Nb. of anodes	32	32	32
Anode size	1.6 m X 0.8 m	1.6 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
Anode stud diameter	18 cm	16 cm	19 cm
Anode cover thickness	16 cm	17.5 cm	10 cm
Nb. of cathode blocks	18	18	18
Cathode block length	3.47 m	3.43 m	3.67 m
Type of cathode block	HC3	HC10	HC10
Collector bar size	20 cm X 10 cm	18 cm X 10 cm	20 cm X 10 cm
Type of side block	HC3	Anthracite	SiC
Side block thickness	15 cm +	15 cm +	10 cm +
ASD	35 cm	35 cm	30 cm
Calcium silicate thickness	3.5 cm	6.0 cm	3.5 cm
Inside potshell size	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m
ACD	5 cm	4.15 cm	4 cm
Excess AlF_3	10.90%	13.50%	13.50%

Ref: M. Dupuis, “Les modèles thermiques”, 2e Symposium québécois sur le procédé d’électrolyse de l’aluminium, CQRDA, 1997.

Summary of the first retrofit study

	Base case		
Amperage	300 kA	265 kA	350 kA
Anode drop	303 mV	273 mV	323 mV
Cathode drop	285 mV	213mV	292 mV
Anode panel heat loss	240 kW	183 kW	284 kW
Cathode bottom heat loss	176 kW	132 kW	202 kW
Operating temperature	973.2 °C	956.1 °C	960.4 °C
Liquidus superheat	6.7 °C	2.4 °C	6.7 °C
Bath ledge thickness	8.66 cm	23.5 cm	9.09 cm
Metal ledge thickness	4.12 cm	9.01 cm	4.42 cm
Current efficiency	94.00%	95.70%	96.10%
Internal heat	628 kW	422 kW	713 kW
Energy consumption	13.72 kWh/kg	11.93 kWh/kg	13.43 kWh/kg

Ref: M. Dupuis, "Les modèles thermiques", 2e Symposium québécois sur le procédé d'électrolyse de l'aluminium, CQRDA, 1997.

Summary of the first retrofit study

- Clearly, a cell designer cannot at the same time aim at maximizing the cell productivity and minimizing the cell energy consumption.
- This is why Rio Tinto per example has developed and is offering both the AP60 and the APXe cells based on the same basic platform.
- Yet, new choice of materials and new and innovative design ideas can always be put to contribution in order to further increase the cell productivity or decrease the cell energy consumption.

Summary of the second retrofit study

	Base case		
Amperage	500 kA	500 kA	600 kA
Nb. of anodes	40	48	48
Anode size	1.95 m X 0.8 m	1.95m X .665m	2.0m X .665m
Nb. of anode studs	3 per anode	4 per anode	4 per anode
Anode stud diameter	20.5 cm	17.5 cm	17.5 cm
Anode cover thickness	10 cm	10 cm	10 cm
Nb. of cathode blocks	24	24	24
Cathode block length	4.17 m	4.17 m	4.17 m
Type of cathode block	HC10	HC10	HC10
Collector bar size	20 cm X 10 cm	20 cm X 10 cm	20 cm X 10 cm
Type of side block	SiC	SiC	SiC
Side block thickness	10 cm +	10 cm +	7 cm +
ASD	30 cm	30 cm	28 cm
Calcium silicate thickness	3.5 cm	3.5 cm	3.5 cm
Inside potshell size	17.8 X 4.85 m	17.8 X 4.85 m	17.8 X 4.85 m
ACD	4 cm	3.5 cm	3.5 cm
Excess AlF_3	13.50%	12.00%	12.00%

Ref: M. Dupuis and V. Bojarevics, "Retrofit of a 500 kA cell design into a 600 kA cell design", ALUMINIUM 87(1/2), 2011, 52-55.

Summary of the second retrofit study

	Base case		
Amperage	500 kA	500 kA	600 kA
Anode drop	354 mV	265 mV	318 mV
Cathode drop	314 mV	87 mV	104 mV
Anode panel heat loss	409 kW	420 kW	449 kW
Cathode bottom heat loss	273 kW	238 kW	240 kW
Operating temperature	963.1 °C	955.6 °C	964.8 °C
Liquidus superheat	9.4 °C	2.6 °C	11.8 °C
Bath ledge thickness	6.15 cm	29 cm	4.76 cm
Metal ledge thickness	2.42 cm	26 cm	1.07 cm
Current efficiency	95.90%	96.50%	96.40%
Internal heat	1043 kW	760 kW	1140 kW
Energy consumption	13.61 kWh/kg	12.1 kWh/kg	13.26 kWh/kg

Ref: M. Dupuis and V. Bojarevics, "Retrofit of a 500 kA cell design into a 600 kA cell design", ALUMINIUM 87(1/2), 2011, 52-55.

Summary of the second retrofit study

- Another tendency is to continue to increase the cell size in order to keep reducing both the cell OPEX and CAPEX.
- It is in that context that the AP60 platform replaced the AP30 platform that itself replaced the AP18 platform.
- It is in that context that the author presented a 500 kA cell design in 2003 and a 740 kA cell design in 2005.

Ref: M. Dupuis, "Thermo-Electric Design of a 500 kA Cell", ALUMINIUM 79(7/8), 2003, 629-631.

Ref: M. Dupuis, "Thermo-Electric Design of a 740 kA Cell, Is There a Size Limit", ALUMINIUM 81(4), 2005, 324-327.

New retrofit study aiming at minimizing cell energy consumption even further

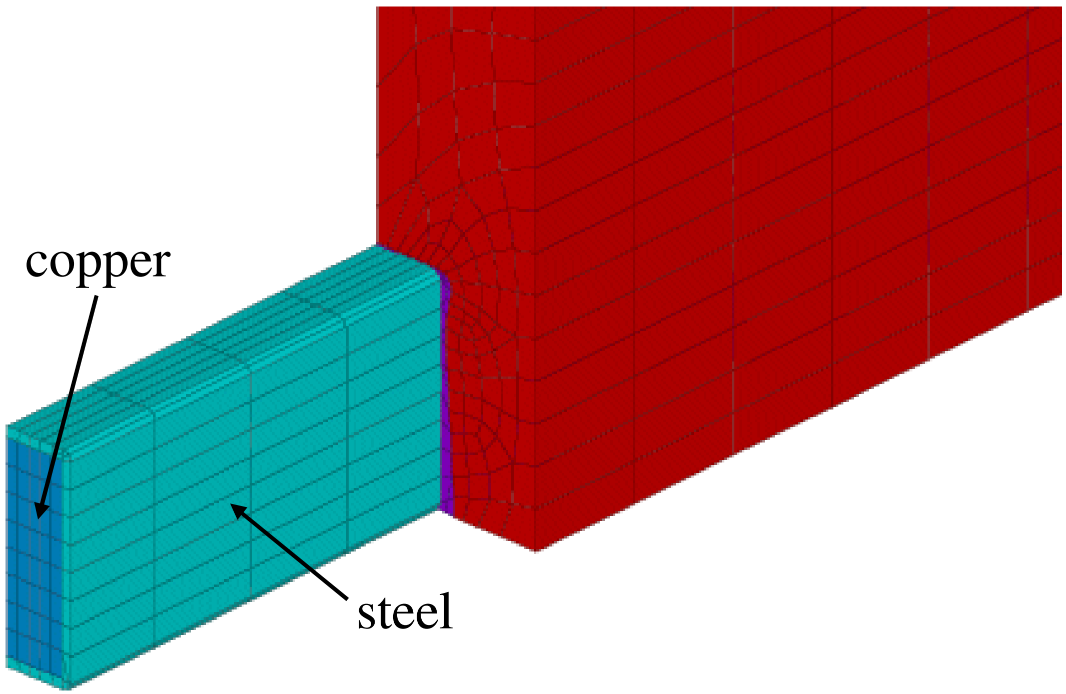
- In the past 30 years, the market conditions of high metal value and the existence of regions of the world offering inexpensive electrical power were favourable for new cell designs maximizing cell productivity while maintaining power efficiency in the 13-13.5 kWh/kg range.
- Technically, 12-12.5 kWh/kg have been achieved multiple times and as for operation at 13-13.5 kWh/kg range, under the current market conditions it might well become the preferable operational range.

New retrofit study aiming at minimizing cell energy consumption even further

- The next question is technically, regardless of market conditions, how much lower can we manage to go?
- Reducing the cell energy consumption means reducing the cell voltage drop which in turn means reducing the cell ohmic resistance.
- Leaving aside the bath ohmic resistance for now, this leaves three distinct ohmic resistances to work with: the anode, cathode and busbar resistances.

Cathode design with copper collector bars

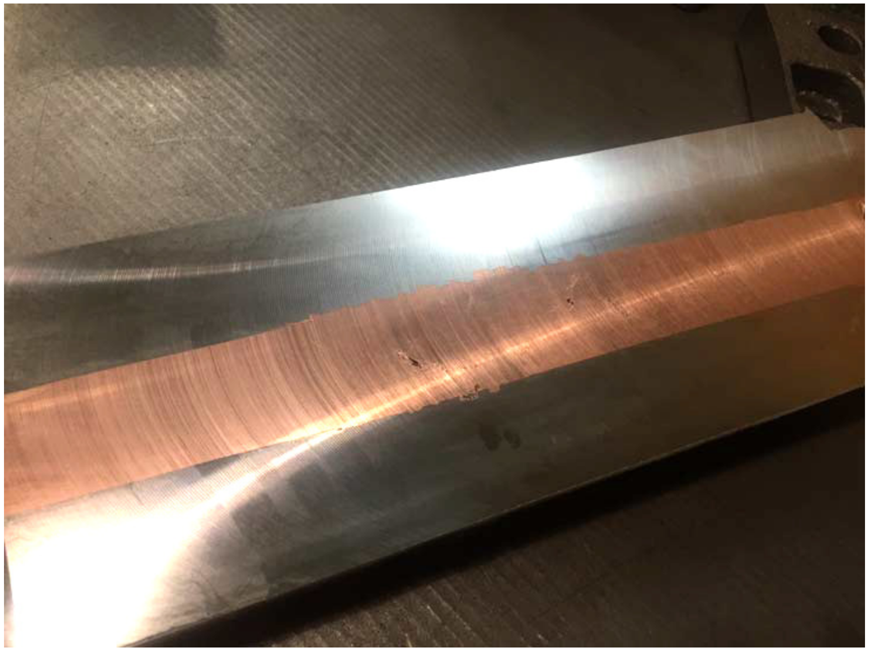
- **As just presented, the 500 kA retrofitted cell is operating at 87 mV at cathode drop by using the following copper collector bars design.**



Ref: M. Dupuis and V. Bojarevics, "Retrofit of a 500 kA cell design into a 600 kA cell design", ALUMINIUM 87(1/2), 2011, 52-55.

Cathode design with copper collector bars

- At the time, it was speculative that such a collector bar design could be actually build, but it is no longer the case.



Ref: Dag Sverre Sæsbøe, Storvik high conductivity anode yoke with copper core, Proceedings of 33rd International ICSOBA Conference, Dubai, UAE, 29 November – 1 December 2015, Paper AL23, Travaux No. 44, 717-726.

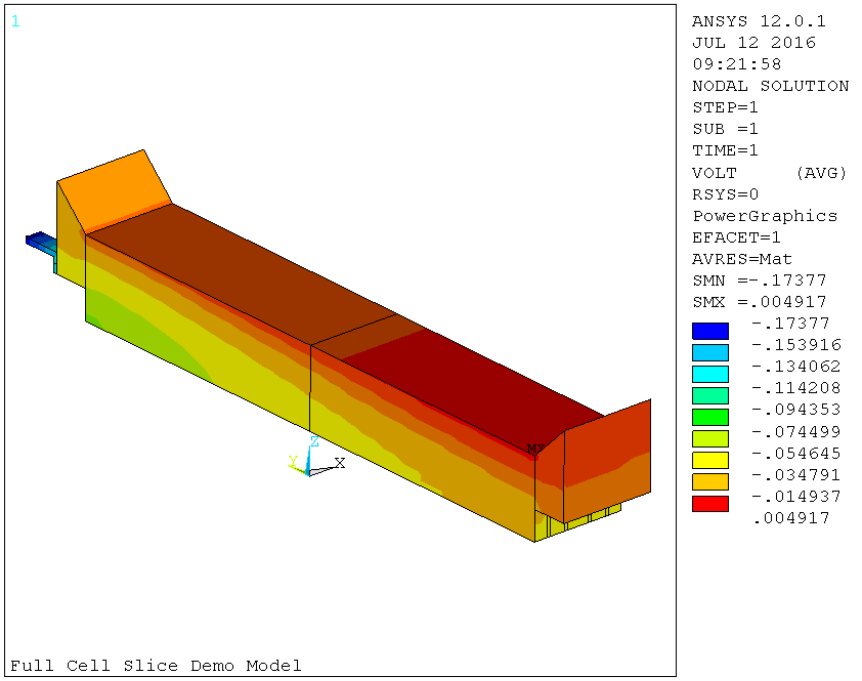
Ref: René von Kaenel and al., Copper Bars for the Hall-Héroult Process, VIII International Congress & Exhibition "NON-FERROUS METALS and MINERALS, Krasnoyarsk, Russia September 13-16, 2016.

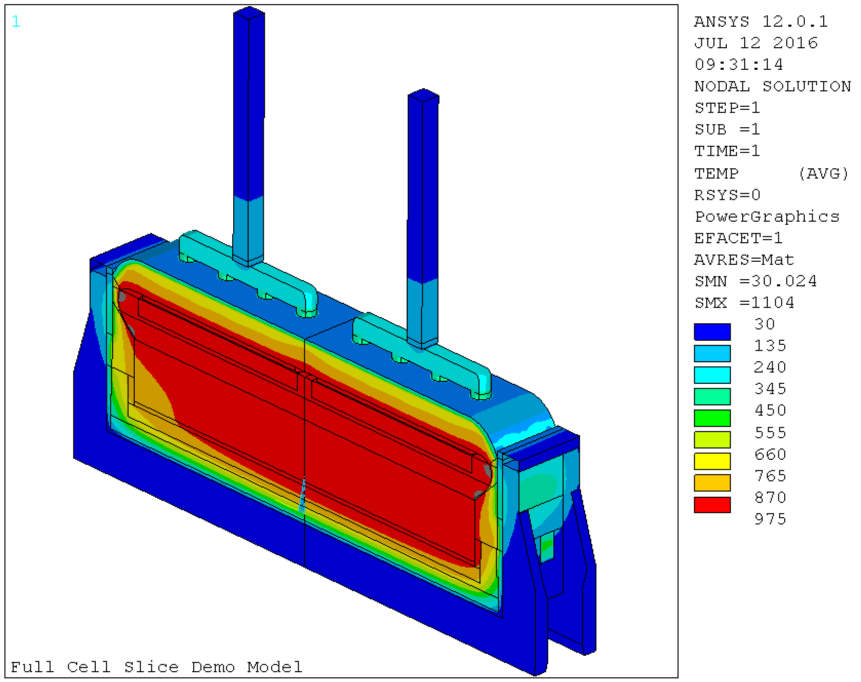
Extracting 100 % of the cell current on the downstream side with copper collector bars

- With the usage of copper collector bars, 100% of the cell current can be extracted on the downstream side without generating excessive horizontal current in the metal pad or producing excessive cathode voltage drop.
- The results previously presented were for a 20 cm x 10 cm copper collector bar size. When the current is extracted all on the downstream side of that cell running at 500 kA, the current density in the bar doubles, and the cathode voltage drop increases from 87 mV to 174 mV.

Ref: M. Dupuis, "New Busbar Network Concepts Taking Advantage of Copper Collector Bars to Reduce Busbar Weight and Increase Cell Power Efficiency", Proceedings of 34th International ICSOBA Conference, Travaux No. 45, Quebec, Canada, 2 – 5 Octobre 2016, Paper AL39.

Extracting 100 % of the cell current on the downstream side with copper collector bars





Ref: M. Dupuis, "New Busbar Network Concepts Taking Advantage of Copper Collector Bars to Reduce Busbar Weight and Increase Cell Power Efficiency", Proceedings of 34th International ICSOBA Conference, Travaux No. 45, Quebec, Canada, 2 – 5 Octobre 2016, Paper AL39.

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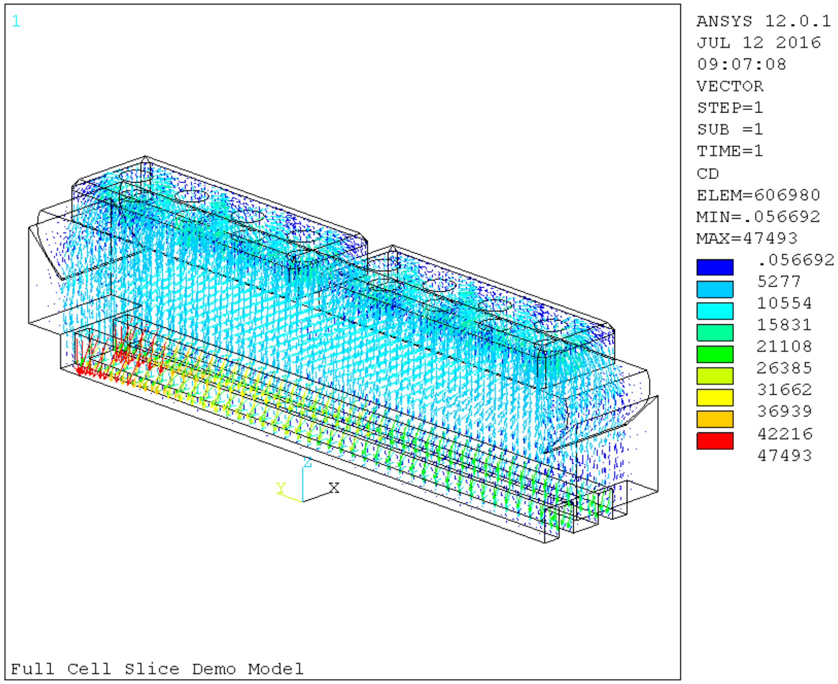

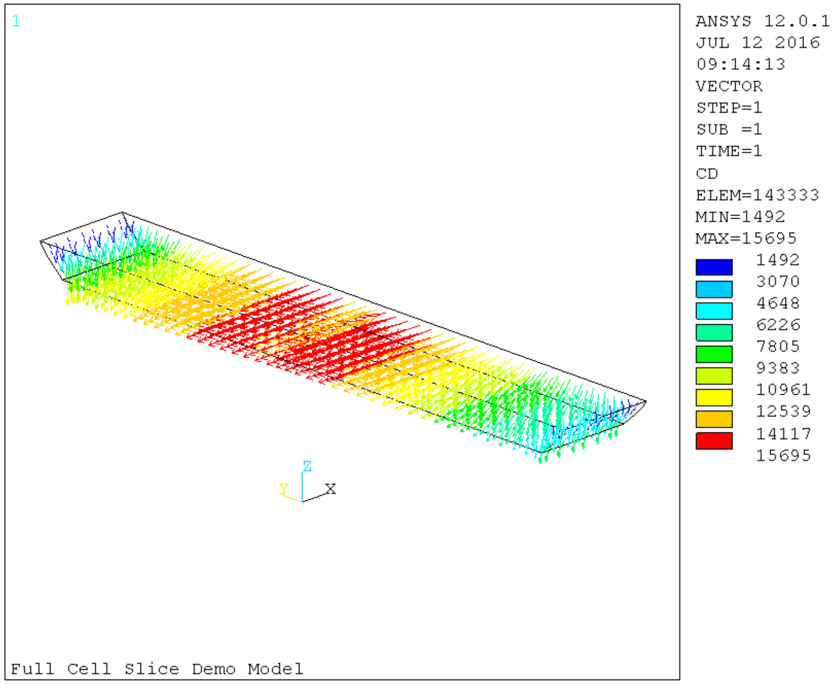

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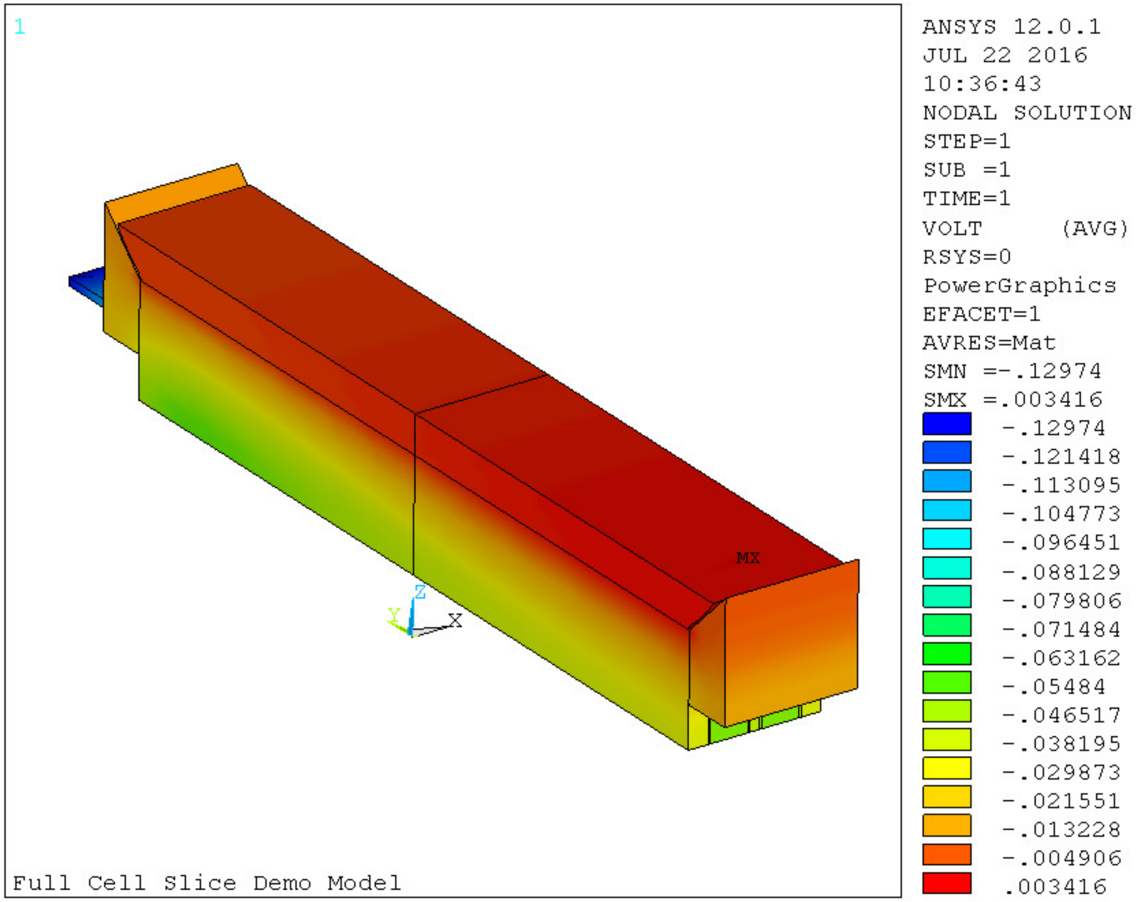
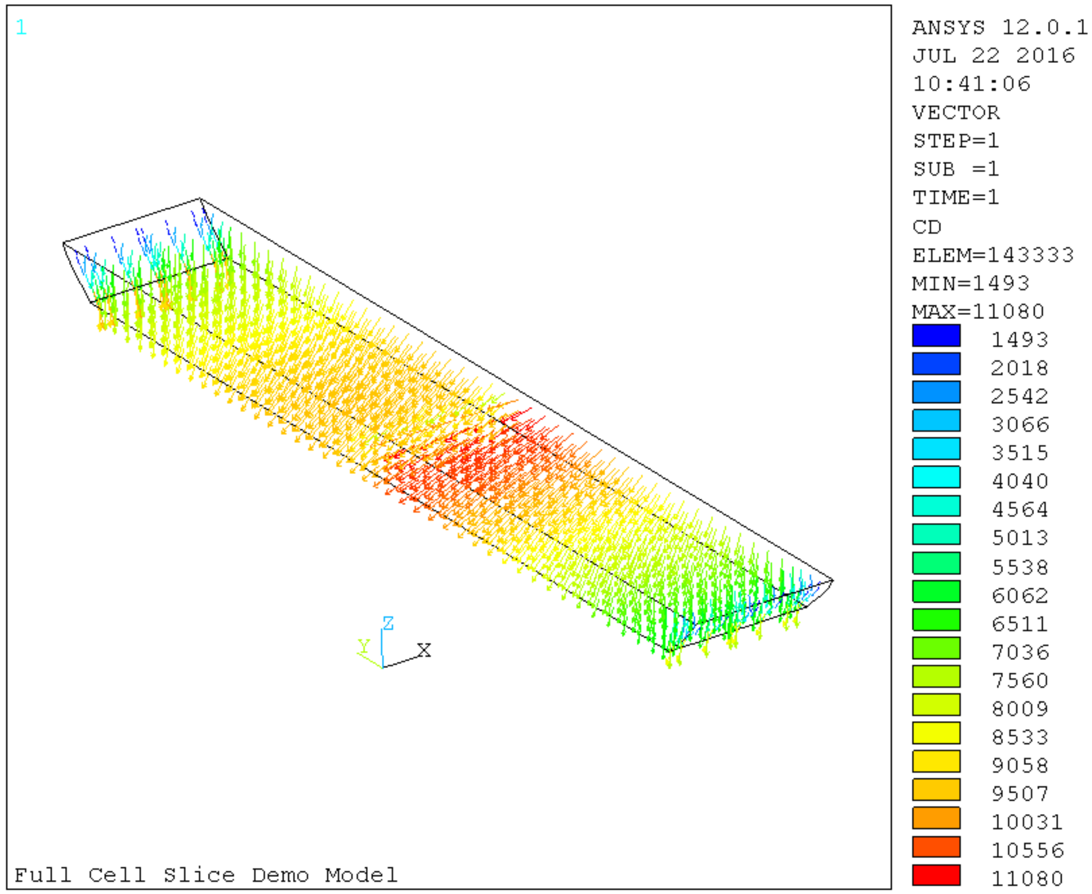
Extracting 100 % of the cell current on the downstream side with copper collector bars

- **New results for a bigger 25 cm x 16 cm copper collector bar. As can be seen, the cathode voltage drop is reduced back to 130 mV.**



Extracting 100 % of the cell current on the downstream side with copper collector bars

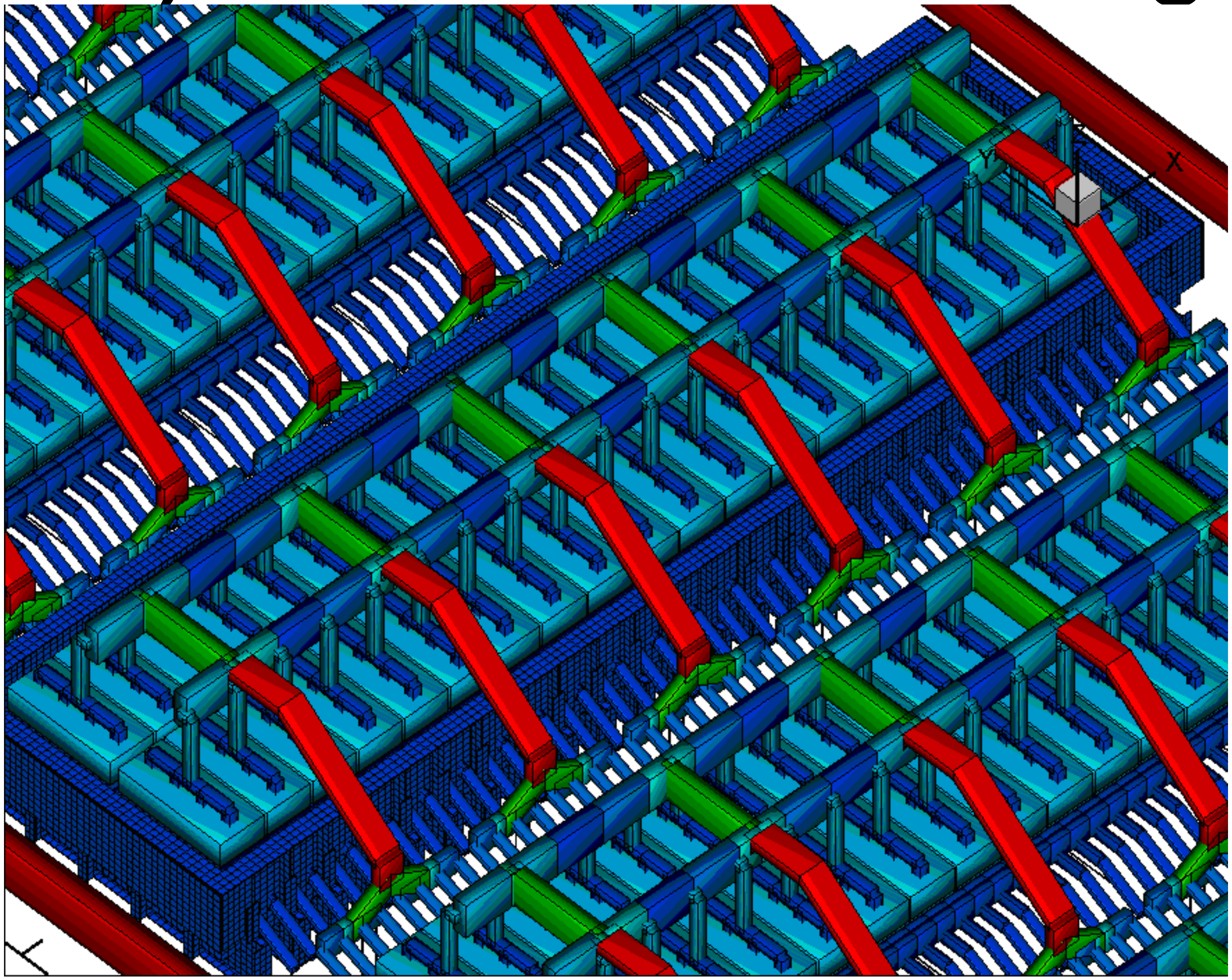
- Resulting horizontal currents in the metal pad. Unfortunately, the center channel creates a gap that prevents the total elimination of that horizontal component.



External compensation current (ECC) busbar network design

- The idea of taking advantage of copper collector bars to extract 100% of the cell current on its downstream side came to the author as a way to reduce of busbar weight.
- In the case of ECC busbar configurations, the busbar network is reduced to only the anode risers so it is the preferable busbar configuration if the main goal is to minimize the busbar voltage drop in order to minimize the cell energy consumption.

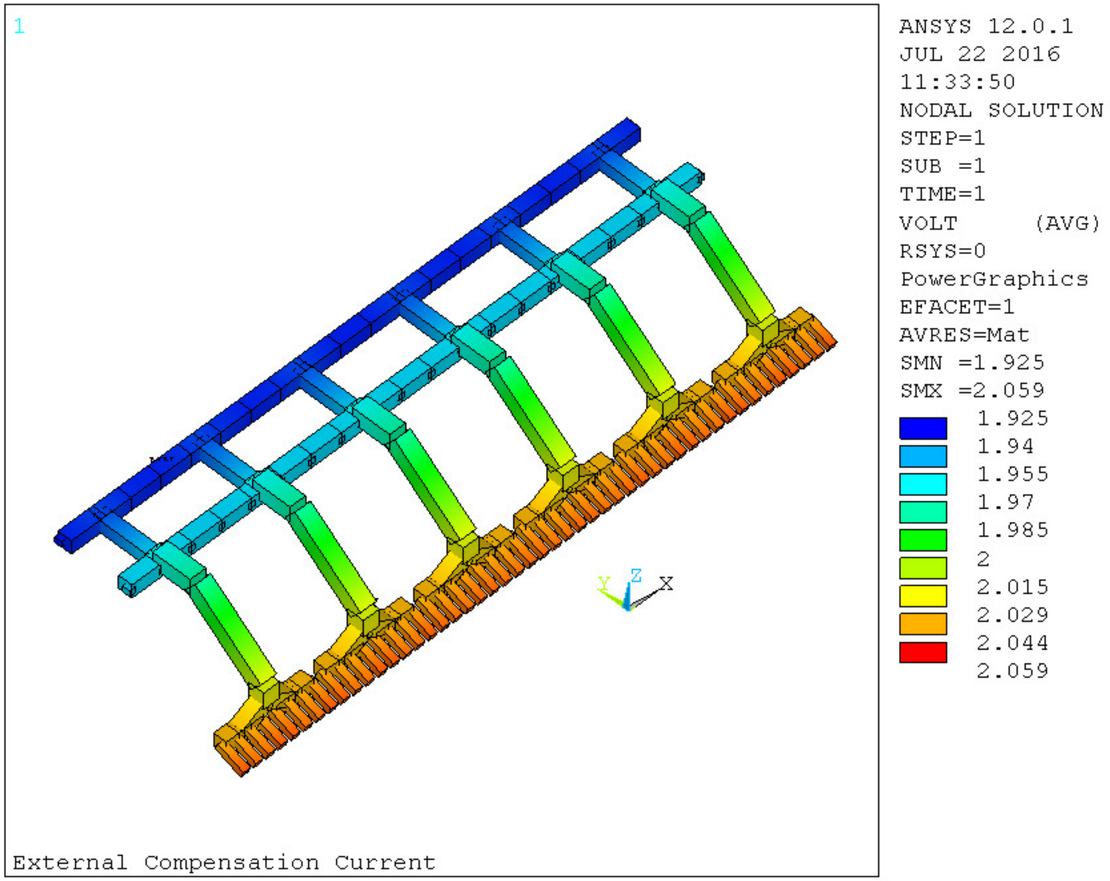
External compensation current (ECC) busbar network design



Ref: M. Dupuis, "New Busbar Network Concepts Taking Advantage of Copper Collector Bars to Reduce Busbar Weight and Increase Cell Power Efficiency", Proceedings of 34th International ICSOBA Conference, Travaux No. 45, Quebec, Canada, 2 – 5 Octobre 2016, Paper AL39.

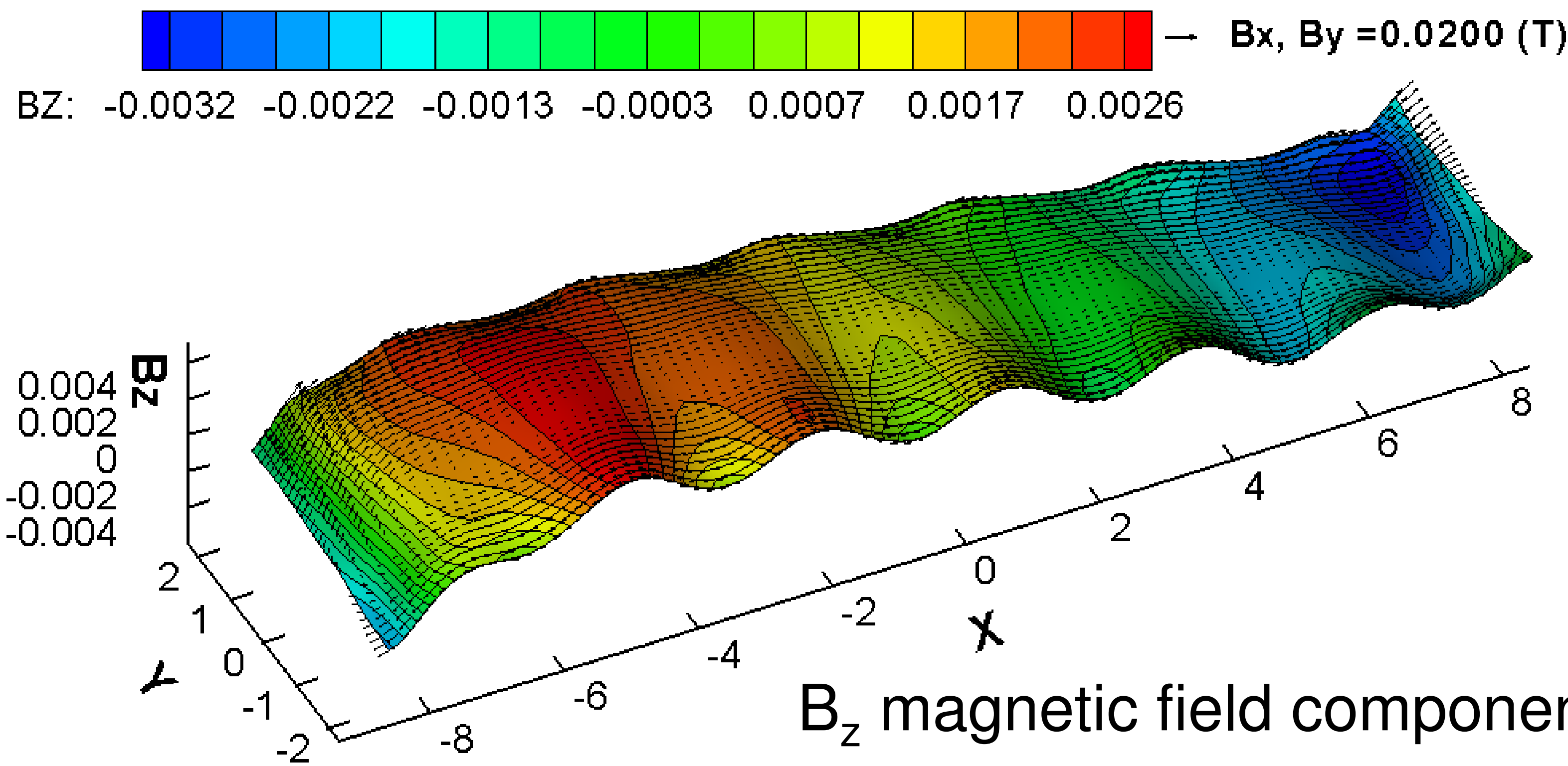
External compensation current (ECC) busbar network design

- The calculated busbar drop for the new, very low current density, design presented here is 134 mV; this design is consistent with a business scenario where the metal cost is low and the energy cost is high.



External compensation current (ECC) busbar network design

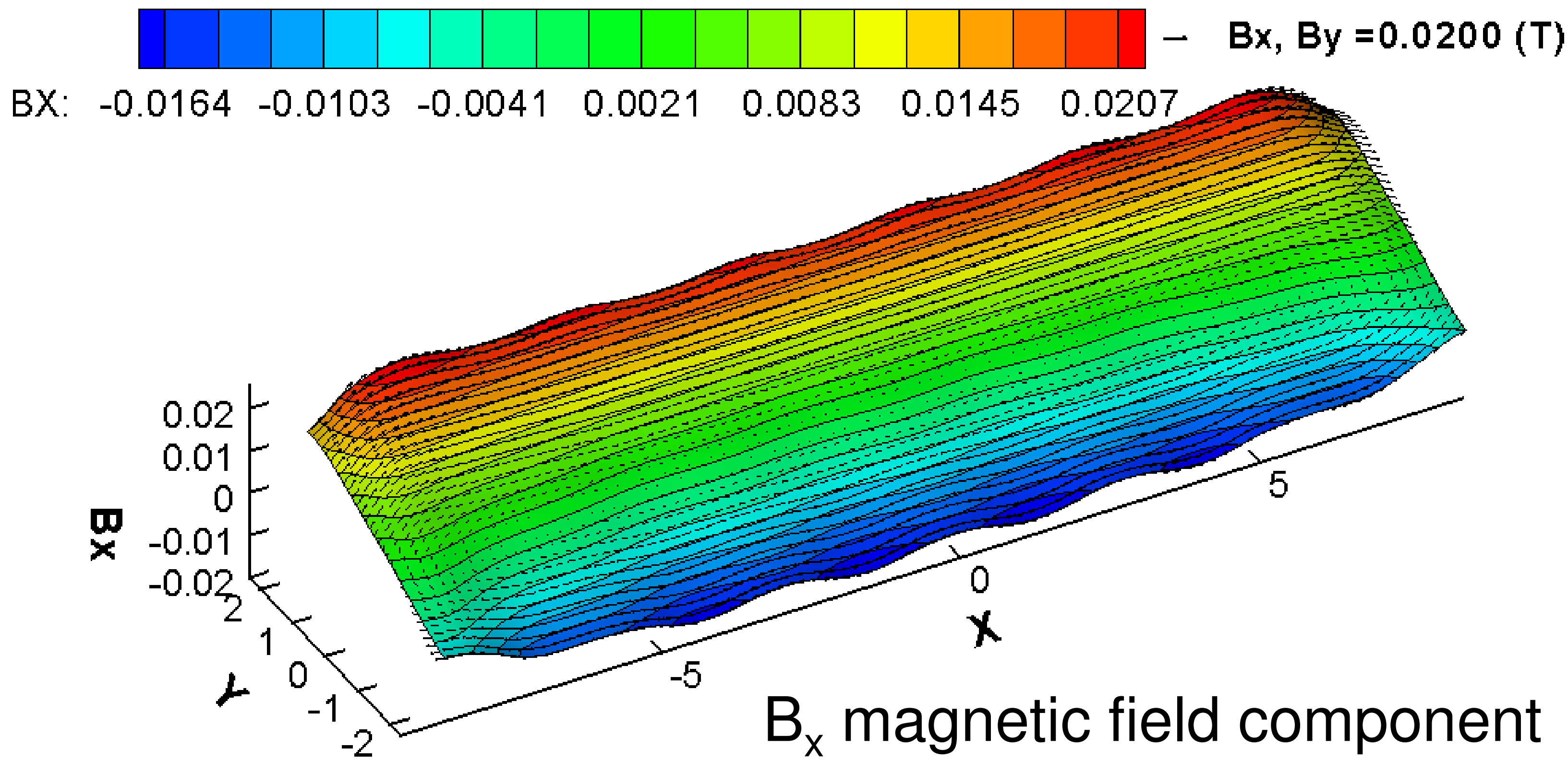
- **Resulting vertical component of the magnetic field (B_z) obtained while using this busbar configuration.**



B_z magnetic field component

External compensation current (ECC) busbar network design

- Resulting longitudinal horizontal component of the magnetic field (B_x) obtained.

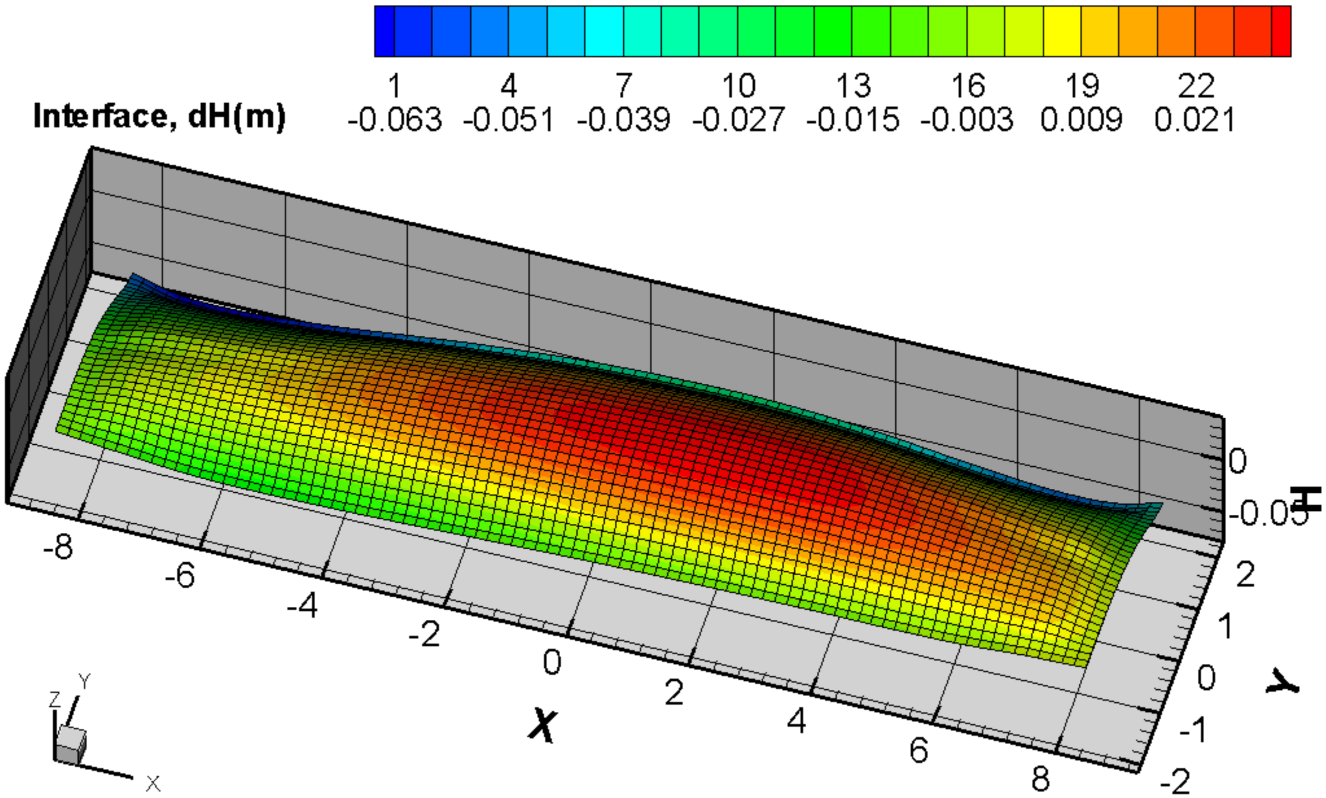


B_x magnetic field component

Ref: M. Dupuis, "New Busbar Network Concepts Taking Advantage of Copper Collector Bars to Reduce Busbar Weight and Increase Cell Power Efficiency", Proceedings of 34th International ICSOBA Conference, Travaux No. 45, Quebec, Canada, 2 – 5 Octobre 2016, Paper AL39.

External compensation current (ECC) busbar network design

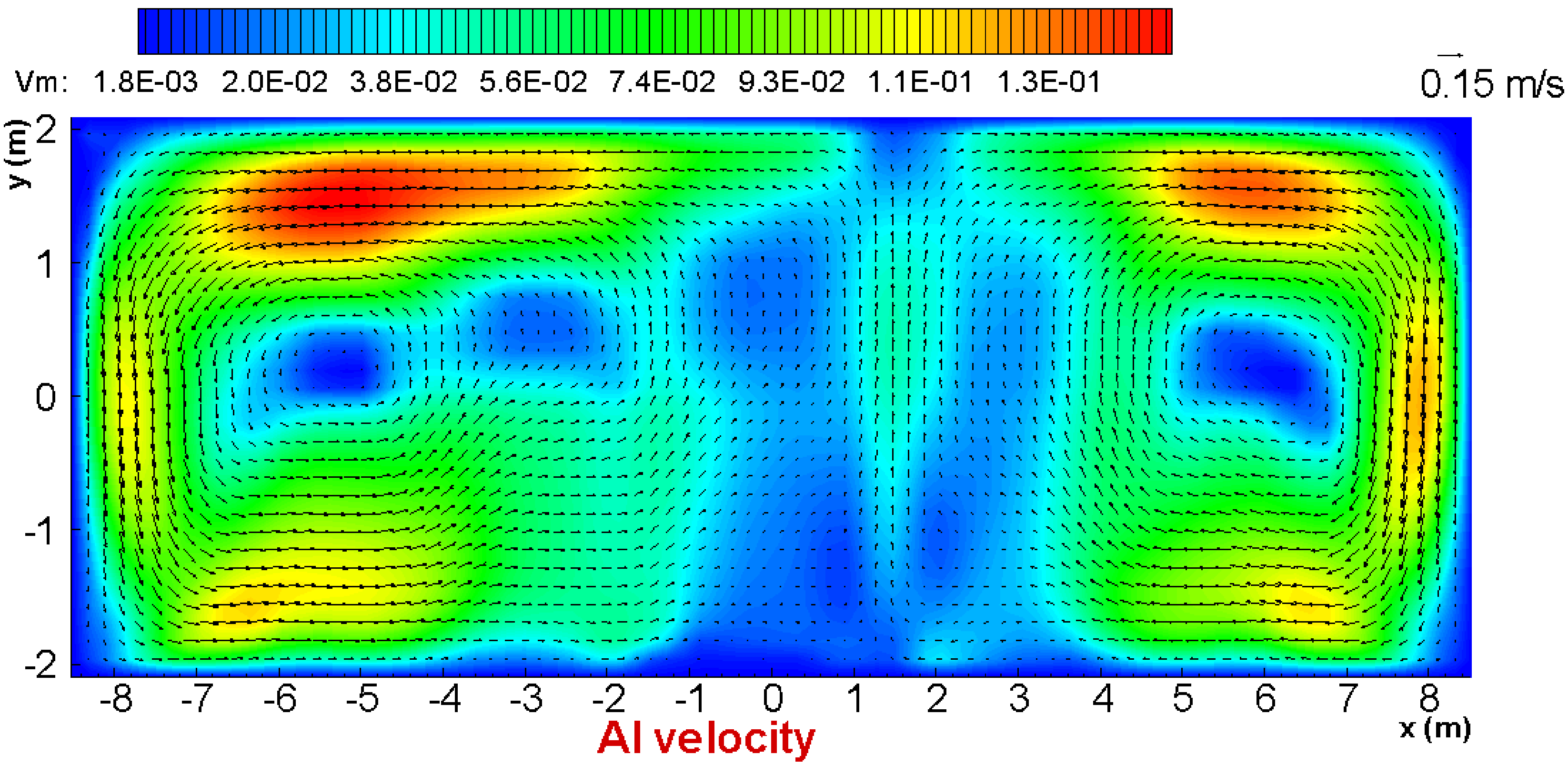
- **Resulting steady-state bath-metal interface deformation.**



Ref: M. Dupuis, "New Busbar Network Concepts Taking Advantage of Copper Collector Bars to Reduce Busbar Weight and Increase Cell Power Efficiency", Proceedings of 34th International ICSOBA Conference, Travaux No. 45, Quebec, Canada, 2 – 5 Octobre 2016, Paper AL39.

External compensation current (ECC) busbar network design

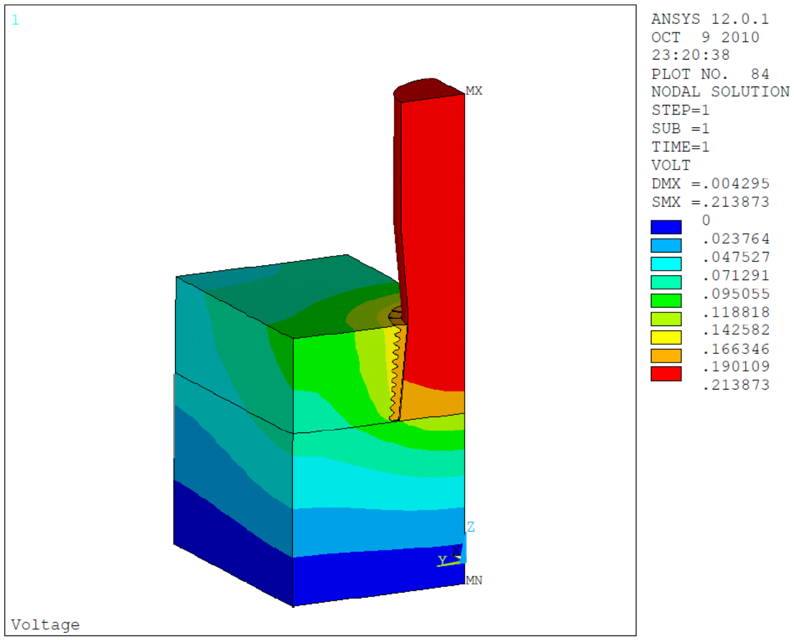
- **Resulting steady-state metal pad flow velocity field.**

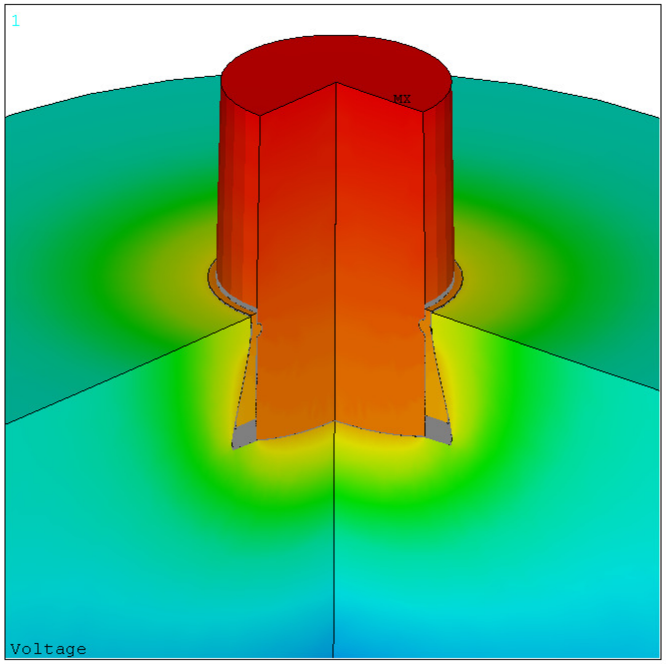


Ref: M. Dupuis, "New Busbar Network Concepts Taking Advantage of Copper Collector Bars to Reduce Busbar Weight and Increase Cell Power Efficiency", Proceedings of 34th International ICSOBA Conference, Travaux No. 45, Quebec, Canada, 2 – 5 Octobre 2016, Paper AL39.

Anode design with innovative stub hole conception

- When operating the cell at 500 kA using 48 anodes of 1.95 m x 0.665 m, the predicted voltage drop is 265 mV due to the usage of an innovative stub hole conception.





Ref: M. Dupuis, "Presentation of a New Anode Stub Hole Design Reducing the Voltage Drop of the Connection by 50 mV", VIII International Congress & Exhibition "Non-Ferrous Metals and Minerals", Krasnoyarsk, Russia, 13 – 16 September 2016

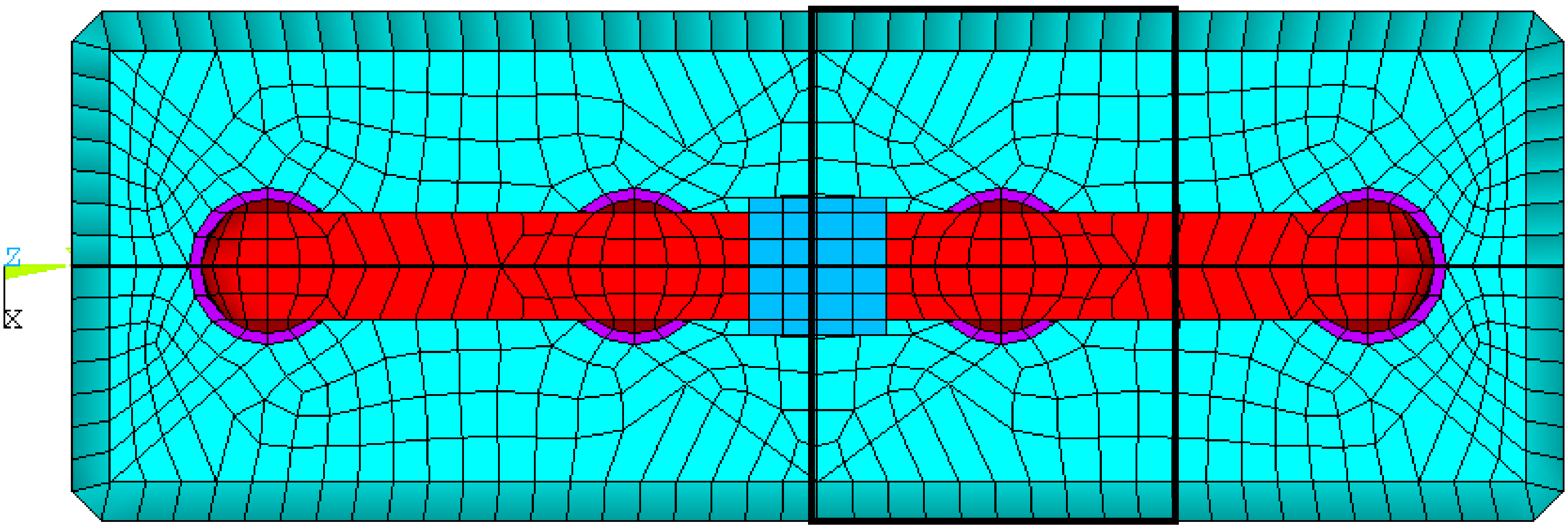
Anode design with innovative stub hole conception

- As previously discussed, the aim of the new design is to get a good contact pressure between the stub bottom horizontal face and the anode stub hole bottom horizontal face. This is achieved by locking the stub vertical thermal expansion. There is more that one way to achieve this, the final optimized shape presented on the right side of the previous slide is less costly to implement, but was developed after the left side design used in the 2011 study.

Ref: M. Dupuis, “Presentation of a New Anode Stub Hole Design Reducing the Voltage Drop of the Connection by 50 mV”, VIII International Congress & Exhibition “Non-Ferrous Metals and Minerals”, Krasnoyarsk, Russia, 13 – 16 September 2016

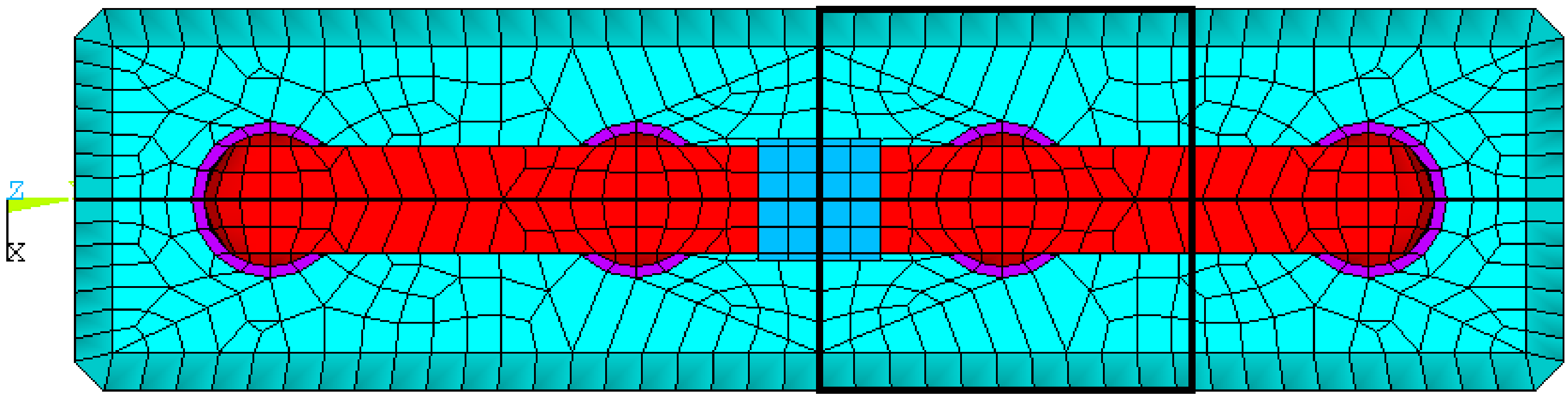
Anode design with innovative stub hole conception

- Ideally, each stub should be feeding a square section of carbon. This is important since with 4 fairly big stubs and the new stub hole design, the biggest resistance is now in the carbon section of the anode.

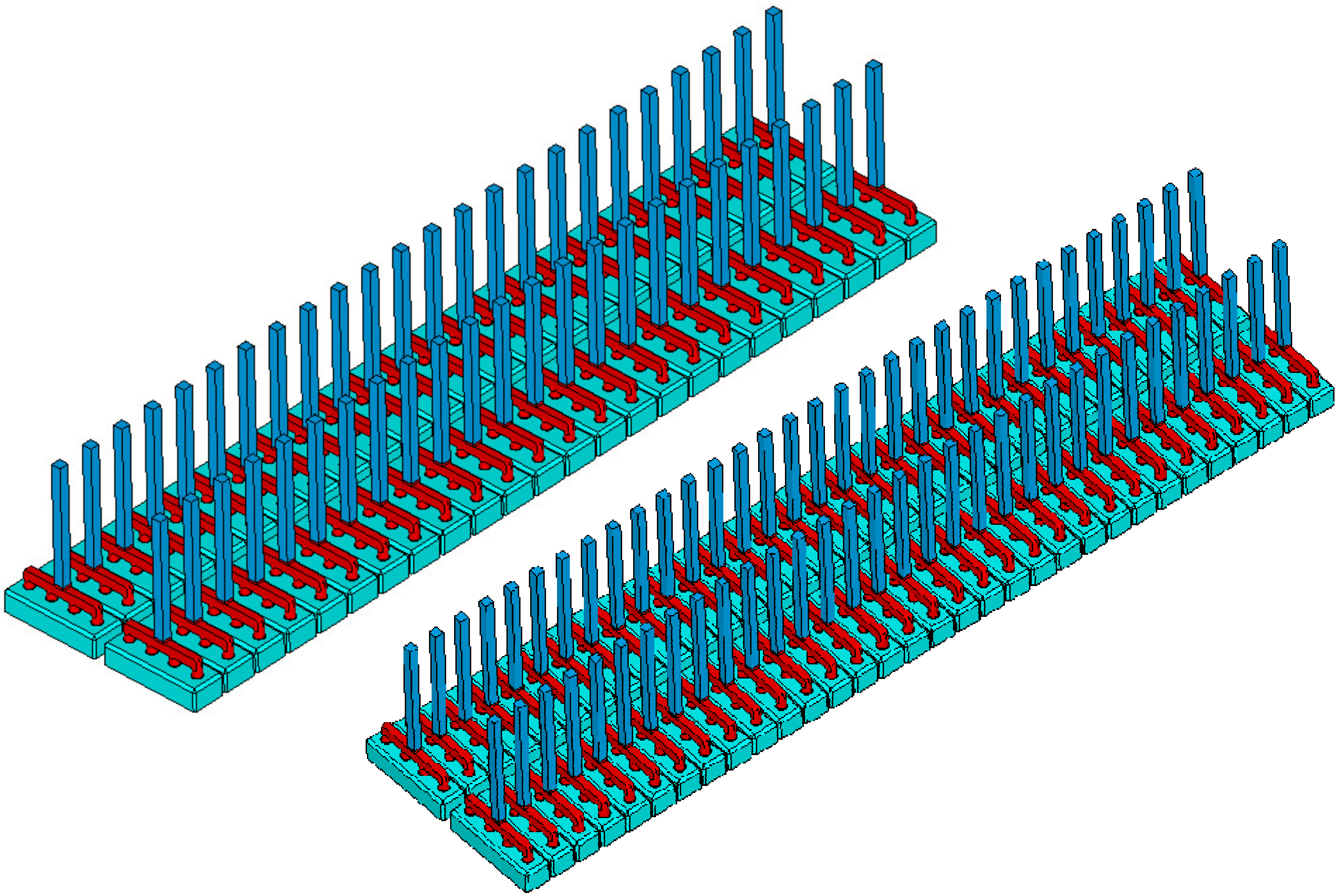


Anode design with innovative stub hole conception

- For that reason, the 48 1.95 m x 0.665 m anodes have been replaced with 64 1.95 m x 0.5 m anodes keeping the exact same stub diameter and stub hole design.

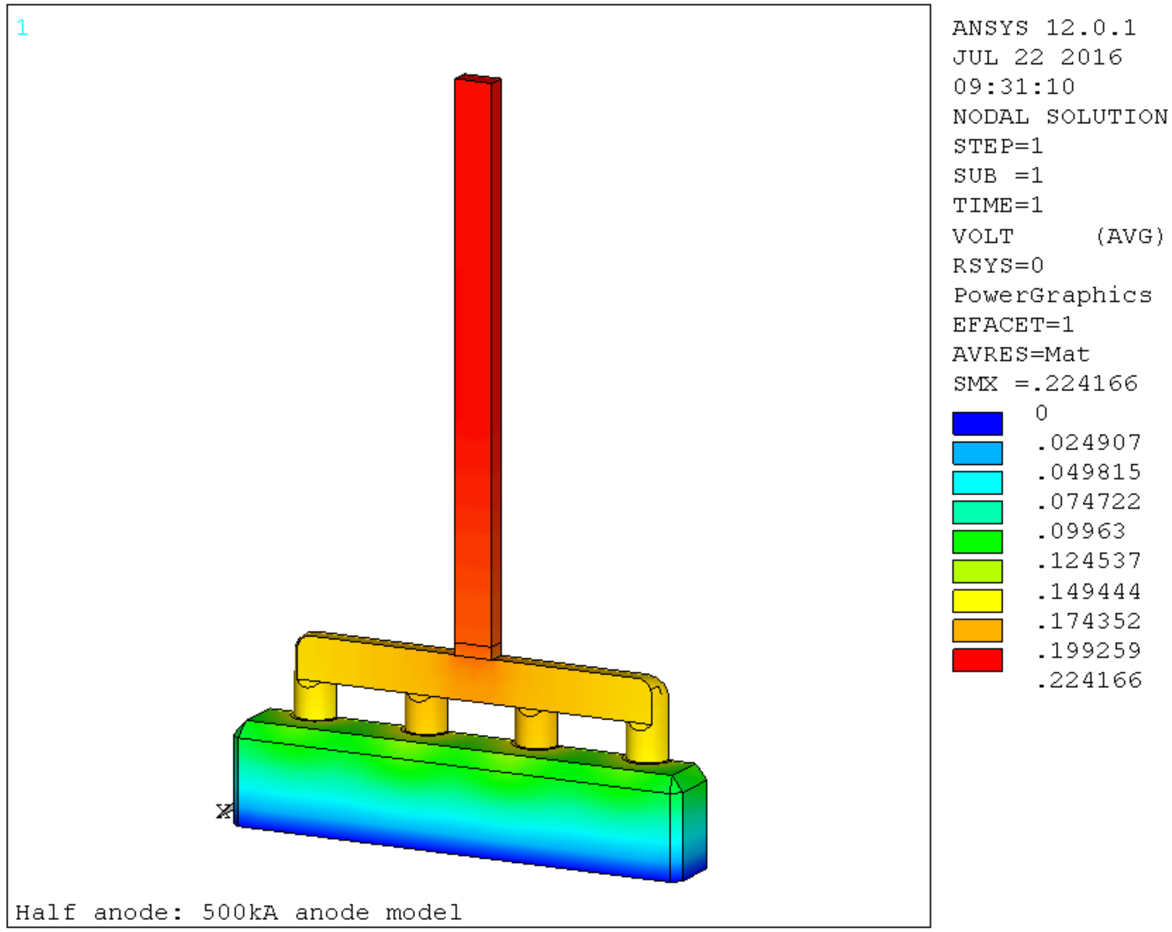


Anode design with innovative stub hole conception



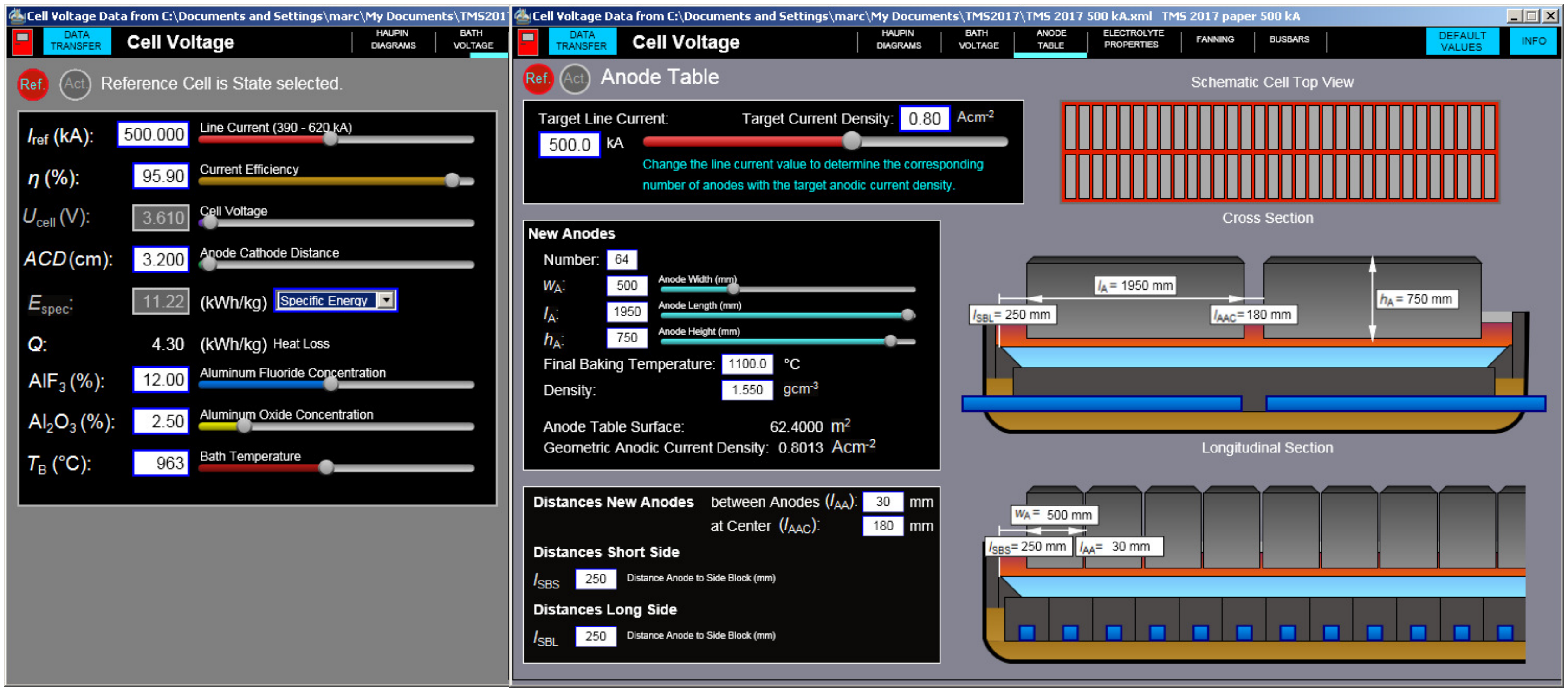
Anode design with innovative stub hole conception

- **Simply by changing the anode aspect ratio and by increasing the number of anodes from 48 to 64, the anode voltage drop has been reduced from 265 mV to 224 mV.**



Calculation of the resulting cell energy consumption

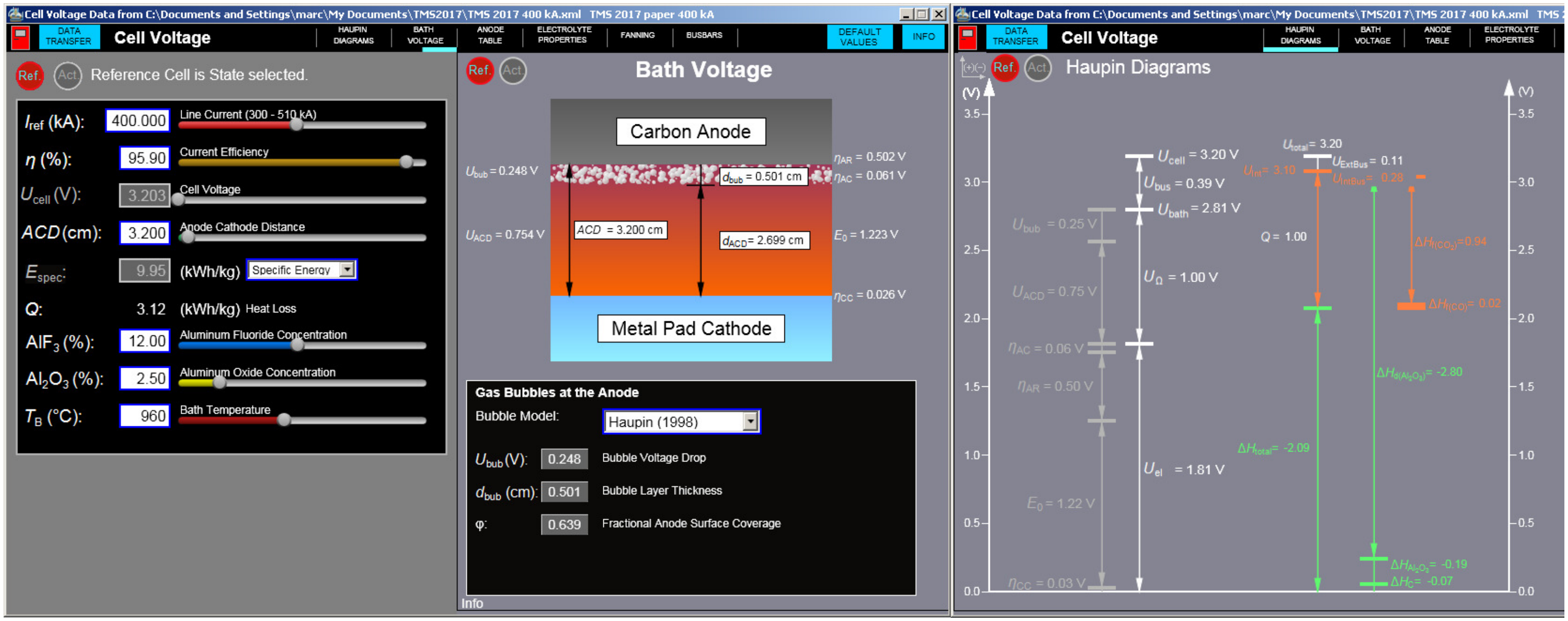
- Several modeling tools could be used to calculate the cell energy consumption from the above results. Peter Entner's CellVolt is one such tool.



Ref: P. Entner, CellVolt AlWeb application: http://peter-entner.com/ug/windows/cellvolt/toc.aspx

Calculation of the resulting cell energy consumption

- At 500 kA and 3.2 cm ACD, the predicted cell energy consumption is calculated to be 11.2 kWh/kg.
- At 400 kA and 3.2 cm ACD, the predicted cell energy consumption is calculated to be 9.95 kWh/kg.



Summary of the present retrofit study

	Base case		
Amperage	500 kA	500 kA	400 kA
Nb. of anodes	48	64	64
Anode size	1.95m X .665m	1.95m X .5m	1.95m X .5m
Nb. of anode studs	4 per anode	4 per anode	4 per anode
Anode stud diameter	17.5 cm	17.5 cm	17.5 cm
Anode cover thickness	10 cm	10 cm	10 cm
Nb. of cathode blocks	24	24	24
Cathode block length	4.17 m	4.17 m	4.17 m
Type of cathode block	HC10	HC10	HC10
Collector bar size	20 cm X 10 cm	25 cm X 16 cm	25 cm X 16 cm
Type of side block	SiC	SiC	SiC
Side block thickness	10 cm +	10 cm +	10 cm +
ASD	30 cm	30 cm	30 cm
Calcium silicate thickness	3.5 cm	3.5 cm	3.5 cm
Inside potshell size	17.8 X 4.85 m	17.8 X 4.85 m	17.8 X 4.85 m
ACD	3.5 cm	3.2 cm	3.2 cm
Excess AlF_3	12.00%	12.00%	12.00%

Summary of the present retrofit study

	Base case		
Amperage	500 kA	500 kA	400 kA
Anode drop	265 mV	224 mV	179 mV
Cathode drop	87 mV	130 mV	104 mV
Busbar drop	310 mV	134 mV	107 mV
Cell voltage	3.89 V	3.59 V	3.20 V
Current efficiency	95.90%	95.90%	95.90%
Internal heat	758 kW	699 kW	414 kW
Energy consumption	12.1 kWh/kg	11.2 kWh/kg	9.95 kWh/kg

Conclusions

- **Two innovations presented by the authors recently at ICSOBA conferences allow to very significantly reducing both the cathode and the busbar voltage drop:**
  - **cathode design with copper collector bars extracting 100% of the cell current on its downstream side**
  - **the usage of modified external compensation current (ECC) busbar configuration made only of anode risers;**

- **They are combined with a third innovation presented at the Aluminiun of Siberia conference:**
  - **the usage of a new anode stub hole design.**

Conclusions

- As a result, a cell operating at 500 kA, 0.8 A/cm^2 of anode current density and 3.2 cm ACD is predicted to have an energy consumption of about 11.2 kWh/kg.

- The same cell platform operating at 400 kA, 0.64 A/cm^2 of anode current density and 3.2 cm ACD is predicted to have an energy consumption of about 9.95 kWh/kg.

Future work

- The cell lining of the cell was previously designed for a cell running at 600 kA and 13.26 kWh/kg in order for that cell to comfortably dissipate 1140 kW with 20 cm x 10 cm size collector bars and 192 anode stubs.
- Using the same cell "platform", the cell internal heat of a cell operating at 400 kA and 9.95 kWh/kg having 25 cm x 16 cm size collector bars and 256 anode stubs is calculated to be reduced to 414 kW which is only 36% of that 1140 kW.
- Clearly a very serious cell lining redesign work will need to be performed as the next step. New "inert" highly insulating materials will certainly need to be added to the list of lining materials for that new lining design to work properly.

Full-Size Chart

Double clicking will take you to a screen where you can create the chart information (alternatively, you can also insert your own chart as a picture/photo/figure).

After creation, right-clicking on the chart will take you to a menu where you can change the chart type.

Please delete this comment when finished.

Bulleted List and Small Chart

Picture/Photo/Figure with Bulleted Text

- Delete text box and insert picture here

Full-Size Picture/Photo/Figure

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