Comparison of the Calculation of the Magnetic Field and the Metal Pad Current Density from Different Models for a 330 kA Cell

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Abstract

This paper compares the magnetic field and the metal pad current density obtained using different mathematical models for a 330 kA cell.

First, an MHD-Valdis model is built using the busbar and potshell geometry defined in the SAMI magnetic model. The SAMI magnetic model [1] is based on ANSYS finite element method while MHD-Valdis magnetic model is based on the boundary element method. The magnetic field results and the CPU time requirement are compared.

Second, GeniSim's parametric CurDen electric model and GeniSim's parametric full cell slice thermo-electric (TE) models are adjusted to represent the 330 kA cell and the metal pad current density results obtained by the SAMI full cell slice model [1]. They are compared with the MHD-Valdis model and GeniSim's parametric models. For the two full cell slice thermos-electric (TE) models, it is only possible to compare the y direction horizontal current density (Jy) while for the CurDen and the MHD-Valdis models, both the horizontal current density in both x (Jx) and y directions are calculated. It was already demonstrated that both Jx and Jy are detrimental to the cell stability, hence Jx needs to be minimized too [2].

Finally, a non-linear transient cell stability analysis is performed using the MHD-VALDIS model, the only model available to perform such a cell stability analysis.

Keywords: Magnetic field, Horizontal current density, Aluminium cell, MHD stability, Mathematical models.

1. Introduction

The present work is a follow up of the work presented in SAMI's TMS 2024 paper [1]. In that paper, the modeling work performed to retrofit a 330 kA cell into a 350 kA cell is presented. Figure 1 of [1] is presenting the busbar layout as implemented in SAMI's ANSYS based magnetic model. This type of ANSYS based magnetic model was first presented in [2]. Figure 1 presents that very first ANSYS based magnetic model mesh, it is showing part of the model that Figure 1 of [1] is now showing, the 3D potshell elements and the 3D space elements inside and outside the cell. Since ANSYS is solving the magnetic field using the finite element method, it is required to mesh the space inside the cell which consists of the liquid zone where we want to know the magnetic field value but also the lining, crust, etc. and the air outside the cell where we do not necessarily want to know the magnetic field but that we need to calculate as well. Solving the magnetic field this way requires between 1 to 1.5 hours of CPU time.

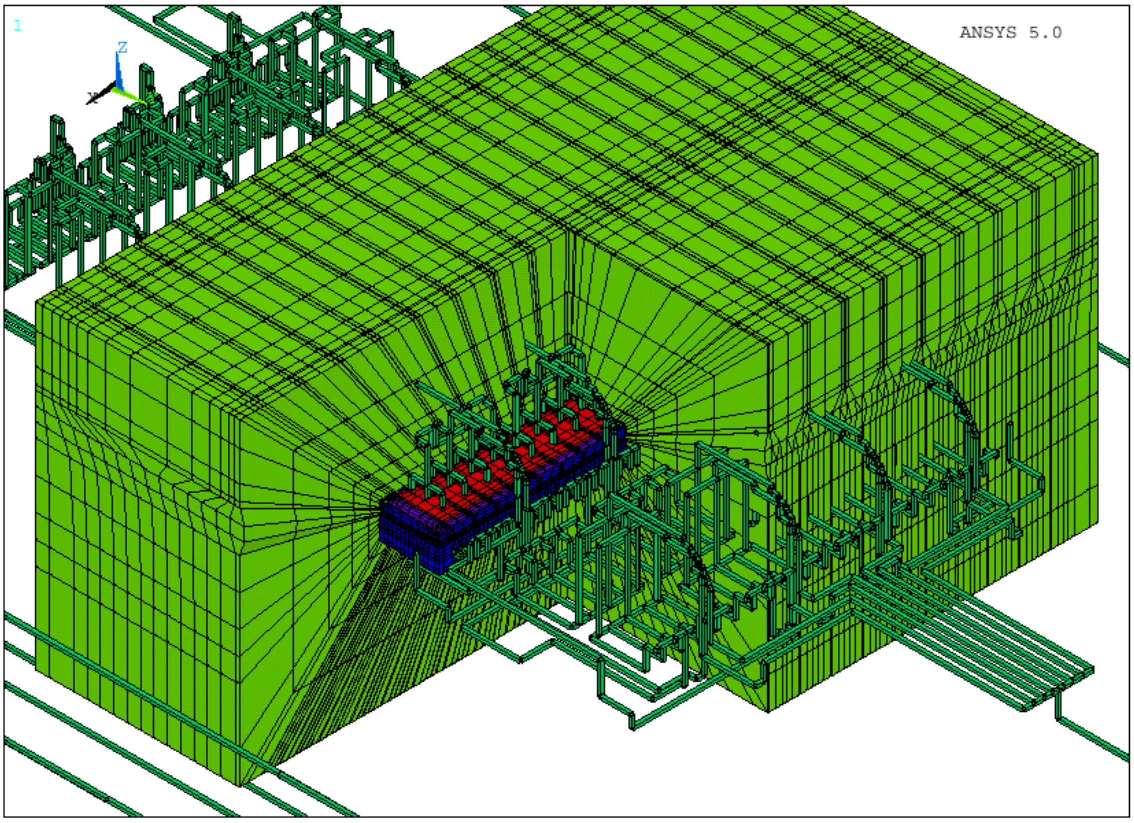

Figure 1. Finite element mesh of the very first ANSYS based magnetic model, reproduced from Figure 6 in [2].

2. MHD-VALDIS Magnetic Model of the Retrofitted 330 kA Cell Operated at 350 kA

It is possible to solve the magnetic field much more quickly using the boundary element formulation instead; which only requires meshing the conductors in 1D and the ferro-magnetic materials (potshell) in 3D as it is done in the software MHD-Valdis.

To solve the magnetic field using MHD-Valdis, it is first required to solve the busbar network thermo-electric problem. The source currents used to solve the magnetic field are coming from the solution of that first problem. In order to do so, the 3D busbar network must be represented as a simplified 1D busbar network that is entered in an input file called BUSNET. Figure 2 presents the 1D busbar layout of the retrofitted 330 kA cell, the colors are representing the obtained currents that will be used to compute the magnetic field. That thermo-electric solution is obtained in few seconds of CPU time.

The next calculation step is to compute the magnetization of the potshell ferro-magnetic material. It is a very non-linear behavior, so solving it requires many iterations. Hence solving that potshell magnetization requires between 30 minutes to 1 hour CPU time depending on the potshell mesh refinement. This must be done from scratch once, but it is possible to save the magnetization results in a file and use these results file after that in order to save this CPU time subsequently. Figure 3 presents the potshell magnetic field, notice that the same simplified potshell geometry that was used in the ANSYS model has been used in MHD-Valdis model.

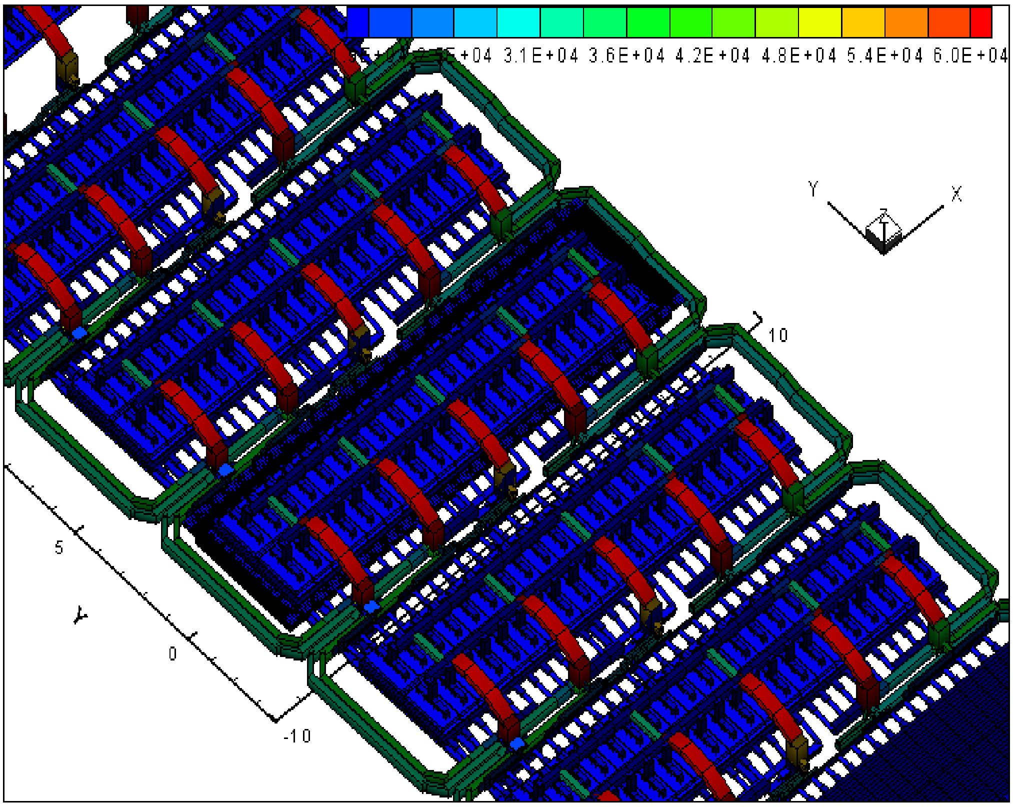

Figure 2. Solution of the 1D electric busbar network by MHD-Valdis for the retrofitted 330 kA cell operated at 350 kA.

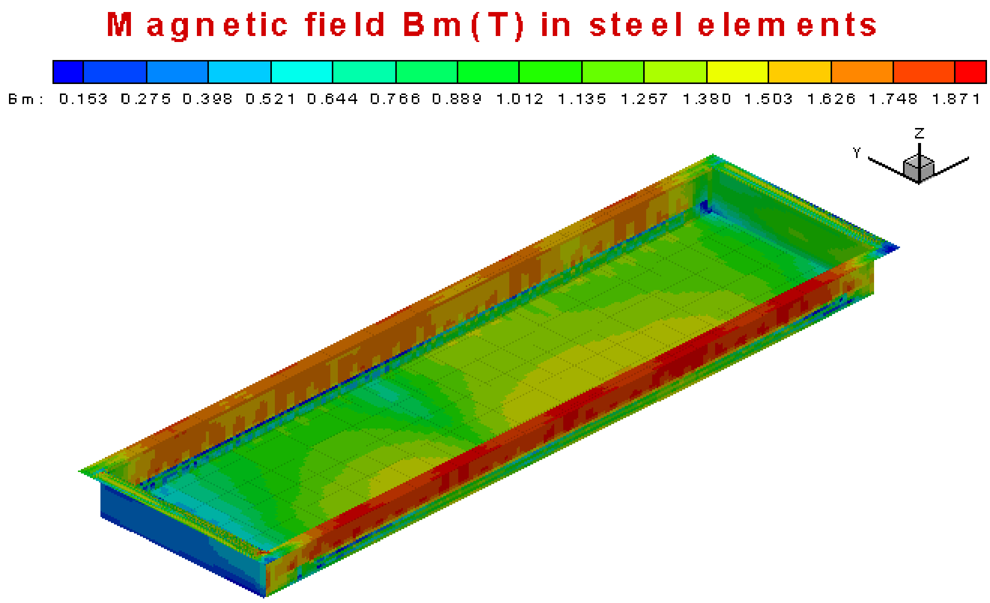

Figure 3. MHD-Valdis potshell magnetic field solution for the retrofitted 330 kA cell operated at 350 kA.

If the file MAGNEZATION.INP is used as input, solving the magnetic field in the bath and metal is done in only few CPU minutes, Figure 4 presents vertical magnetic field component results computed at the bath-metal interface level for the retrofitted 330 kA cell operated at 350 kA. This solution is quite similar to the one obtained using the ANSYS magnetic model presented in Figure 3 of [1].

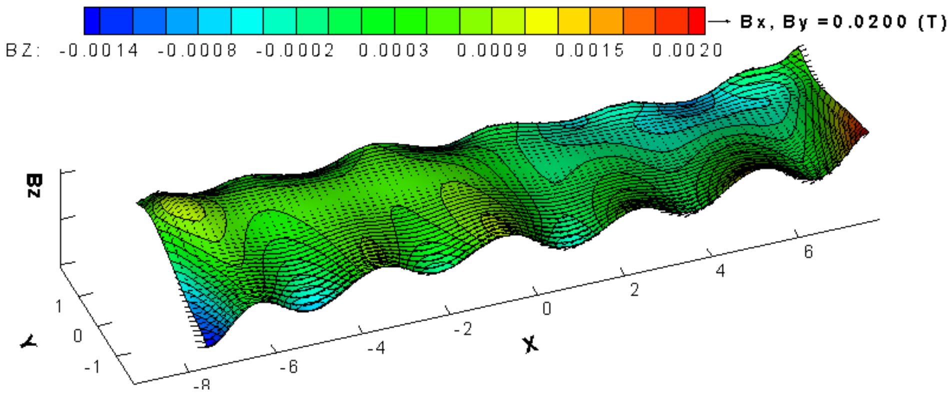

Figure 4. MHD-Valdis vertical component magnetic field solution for the retrofitted 330 kA cell operated at 350 kA at the bath-metal interface level.

3. MHD-Valdis Electric Solution for the Retrofitted 330 kA Cell Operated at 350 kA

As already presented above, the MHD-Valdis software solves for the busbar network electric problem before solving for the magnetic field as it is using the obtained currents as sources for the Biot-Savart integration procedure. All the source currents are considered, including those in the liquid metal. Figure 5 presents the three components of the middle of the metal pad current density.

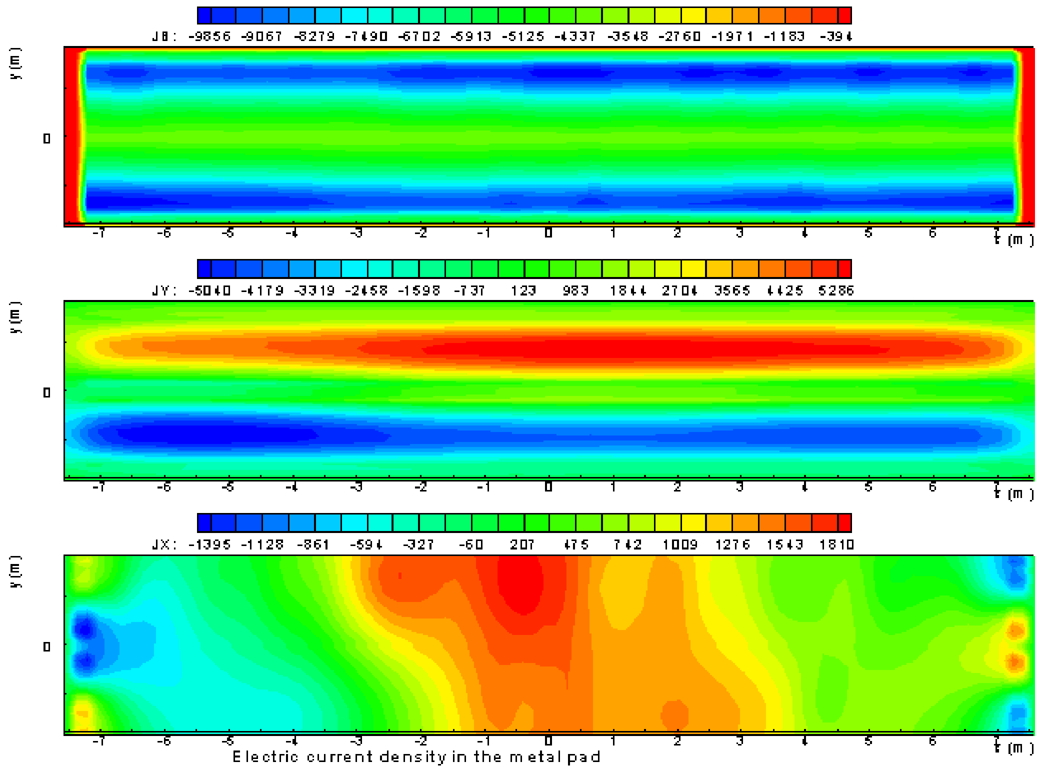

Figure 5. MHD-Valdis middle of the metal pad calculated current density for the retrofitted 330 kA cell operated at 350 kA, Jz on top, Jy in the middle and Jx at the bottom.

4. ANSYS 3D CurDen Electric Model of the Retrofitted 330 kA Cell Operated at 350 kA

An ANSYS based generic 3D electric full cell model was also developed as part of the very first ANSYS magnetic model, it is presented in Figure 4 of [2]. Since it is totally generic, any cell technology can quickly be represented by setting up the different parameter values. Figure 6 presents the mesh of the retrofitted 330 kA cell. As the model's name indicates, this model is used to compute the metal pad current density. Since the collector bar current pickup affects the metal pad current density, the current pickup calculated by the MHD-Valdis model was used as boundary conditions in the CurDen model. The resulting current density in the middle of the metal pad in presented in Figure 7.

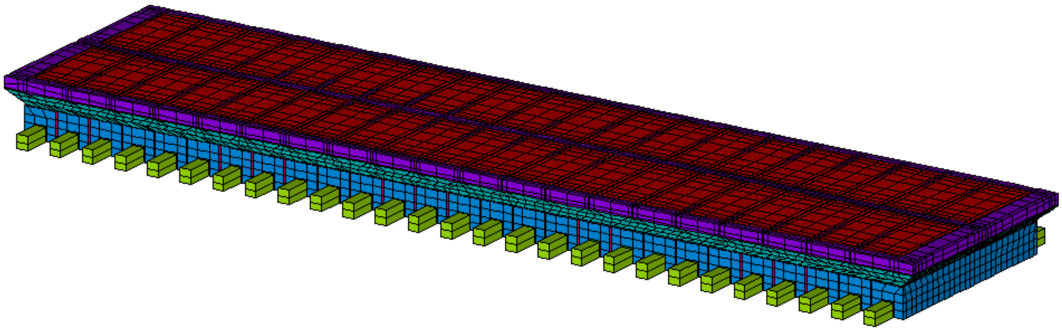

Figure 6. Mesh of the ANSYS 3D CurDen electric model for the retrofitted 330 kA cell

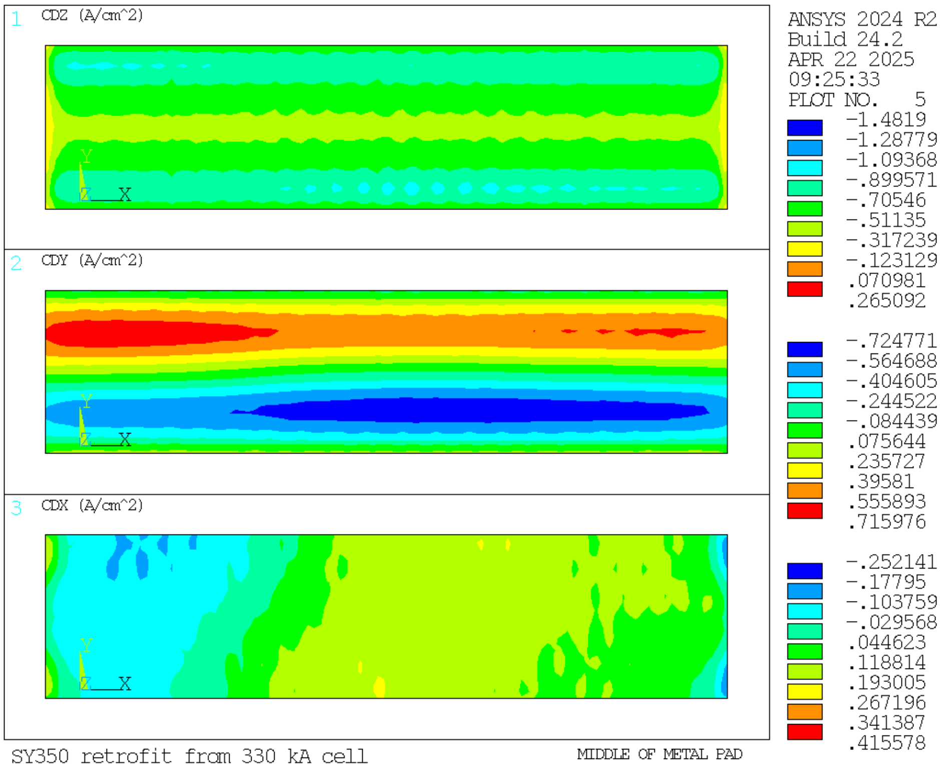

Figure 7. Middle of the metal pad current density calculated by the ANSYS 3D CurDen electric model for the retrofitted 330 kA cell operated at 350 kA, Jz on top, Jy in the middle and Jx at the bottom.

5. ANSYS 3D Thermo-Electric Cathode Side Slice Model of the Retrofitted 330 kA Cell Operated at 350 kA

Another type of model that was been developed is an ANSYS based 3D thermo-electric cathode side slice with liquid zone model. Usually, cathode side slice models are used to calculate the cathode voltage drop, the cathode heat loss and the ledge profile at a user specified cell superheat. When the liquid zone is added with electrical only elements, that model can also calculate the metal pad horizontal current in the transverse direction (Jy). Figure 8 presents the cathode side slice model geometry while Figure 9 presents the obtained Jy at the middle of the metal pad along the width of the cell. This type of model cannot calculate the horizontal current in the longitudinal direction of the cell (Jx) and is only representative of the Jy away from the cell corners and it is assuming a uniform collector bars current pickup.

6. Excel Electric Cathode Assembly Model of the Retrofitted 330 kA Cell Operated at 350 kA

An Excel electric cathode assembly model has also been used to compute the Jy. That type of relatively simple model has been used recently to calculate the Jy in different cathode assembly designs proposed by Elken China [3, 4]. It has been demonstrated in [3, 4] that the Excel model can accurately compute the Jy of many different types of cathode assembly configurations. The purpose of computing Jy using several independent models is to partially validate the model solutions as it is not possible to measure the metal pad current density in order to validate such a model with real cells' data. Figure 10 presents the Jy obtained by the 4 models presented here. As we can see in Figure 10, all the results are quite comparable and are also very comparable to those presented in Figure 4 of [1].

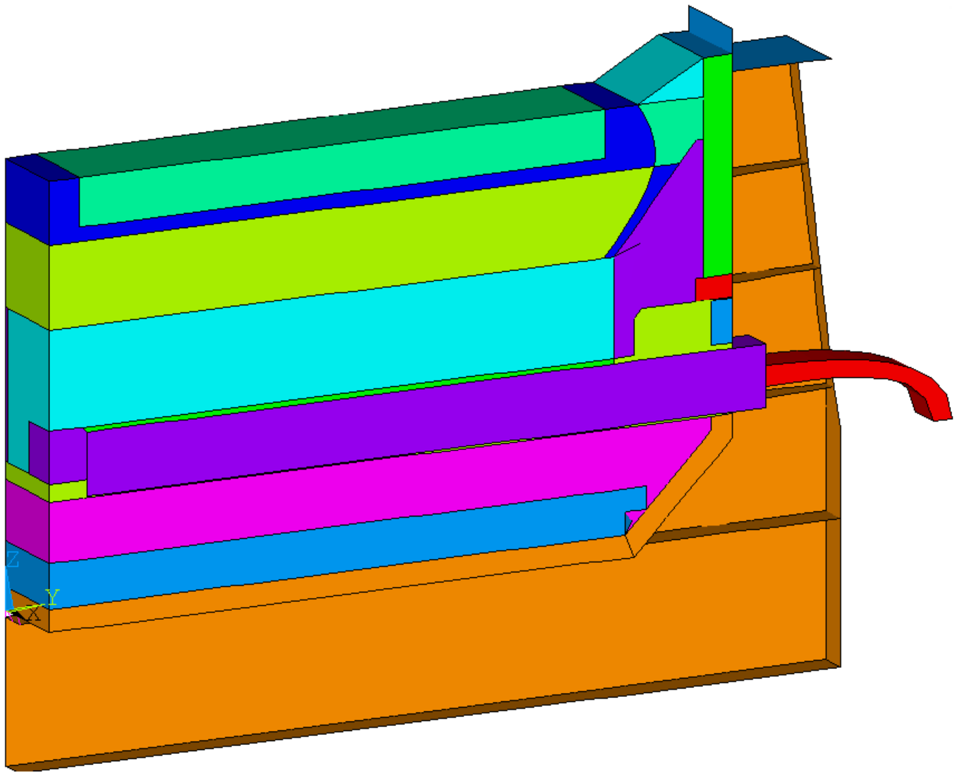

Figure 8. Geometry of the ANSYS 3D cathode side model for the retrofitted 330 kA cell.

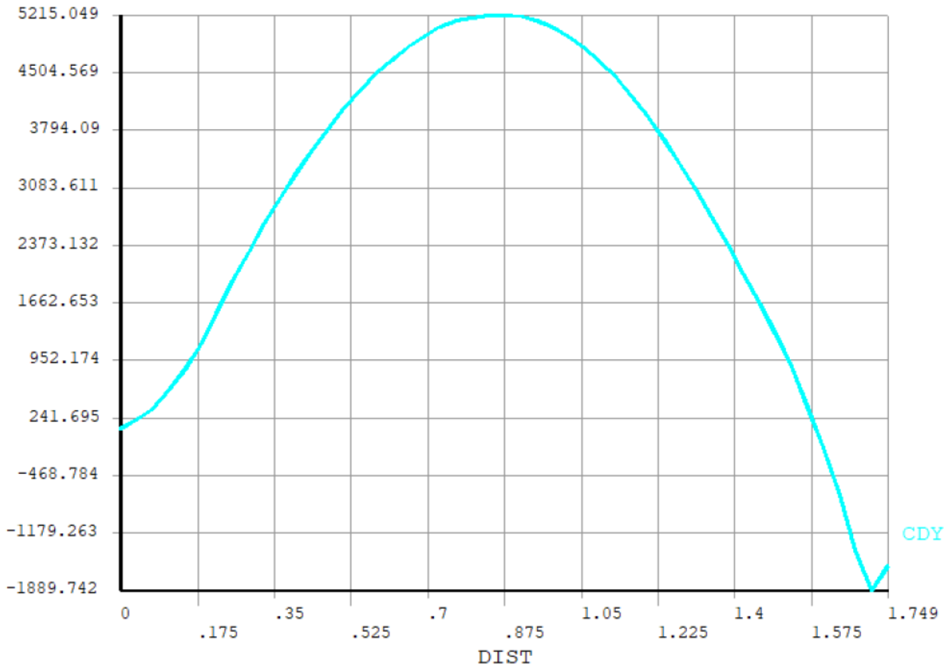

Figure 9. Middle of the metal pad horizontal current density (Jy) calculated by the ANSYS 3D side slice TE model for the retrofitted 330 kA cell operated at 350 kA.

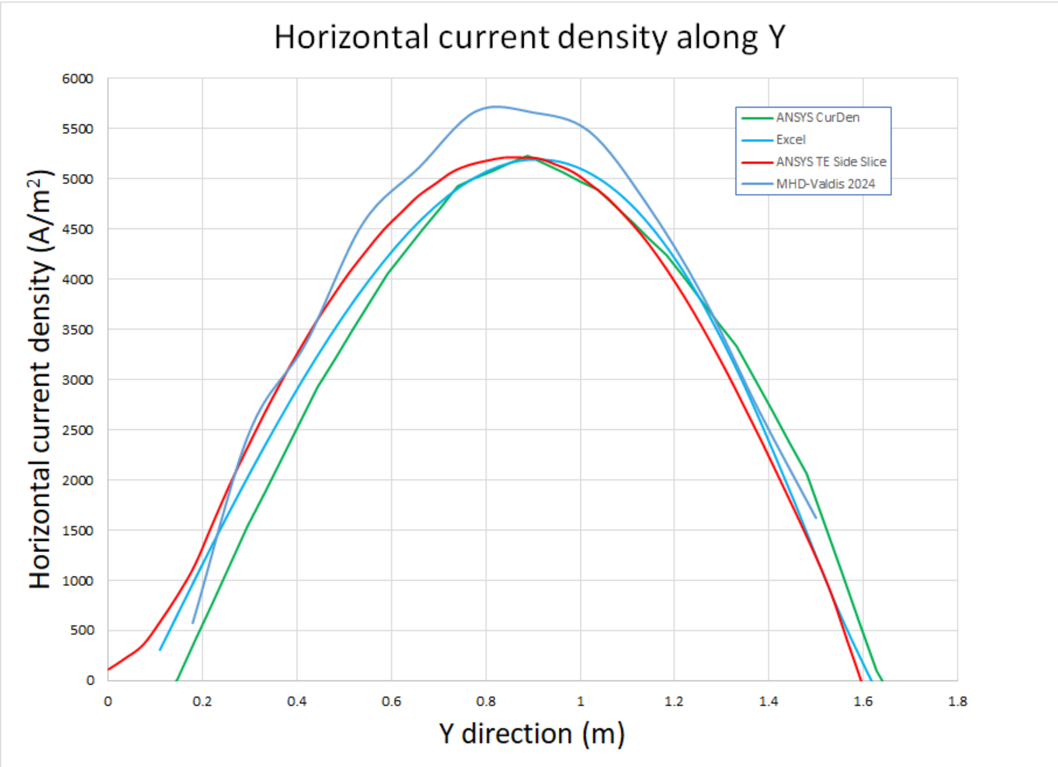

Figure 10. Comparison of the metal pad horizontal current density (Jy) calculated by the Excel electric cathode assembly model and the other 3 previous models.

7. MHD-Valdis Steady-State Flow Solution from Shallow Water CFD Model of the Retrofitted 330 kA Cell Operated at 350 kA

After solving first for the current in the busbar network with the electric model and the magnetic field with the boundary element model, the MHD code solves next for the steady state flow in the bath and metal and for the bath-metal interface deformation using the shallow water CFD model that apply the previously computed Lorentz forces. This CFD model accounts for the turbulence in the flow using a k-ω turbulence model. The CFD model contains one user defined parameter, CF, which is the friction coefficient between the cavity boundaries and the 2 fluids. For the results presented below, CF was adjusted to 0.02.

Figure 11 presents the obtained steady state metal flow solution, while Figure 12 presents the obtained steady state bath/metal interface deformation. The code took about 30 minutes CPU time to compute this solution which includes an iterative procedure to adjust the shape of the anode bottom face to ensure a constant bath thickness under the anode (ACD), despite the deformation of the bath-metal interface.

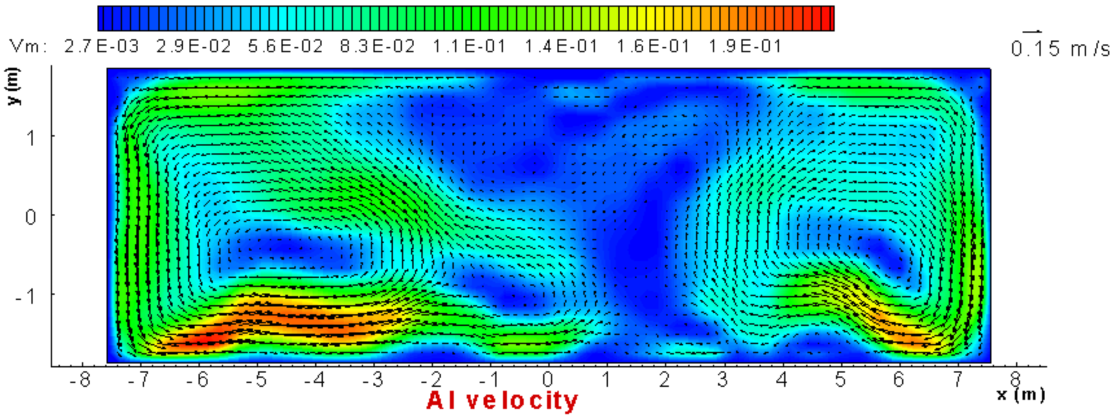

Figure 11. Steady state metal flow computed by the MHD-Valdis shallow water CFD model for the retrofitted 330 kA cell operated at 350 kA.

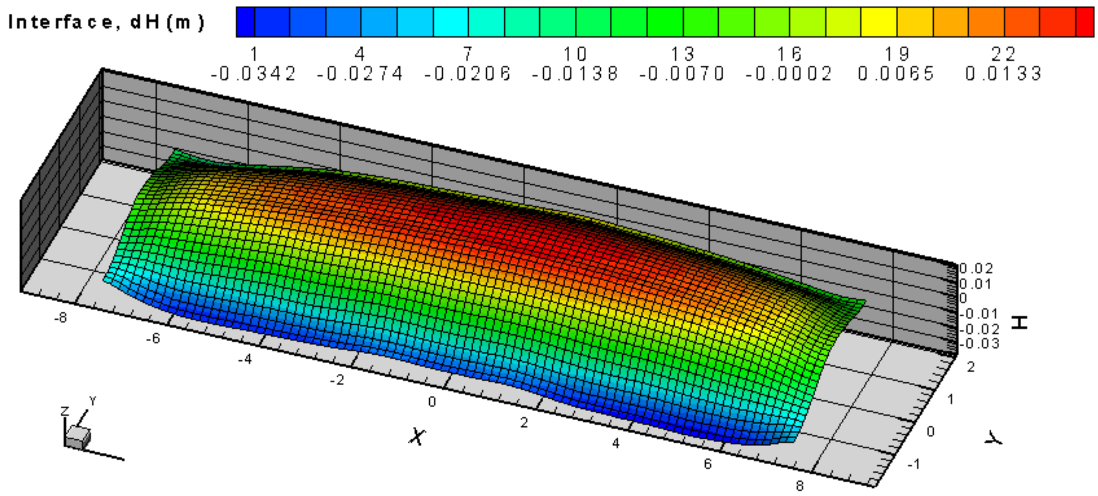

Figure 12. Steady state bath-metal interface computed by the MHD-Valdis shallow water CFD model for the retrofitted 330 kA cell operated at 350 kA.

8. MHD-Valdis Cell Stability Analysis Model Results of the Retrofitted 330 kA Cell Operated at 350 kA

Once the steady state CFD solution has been calculated, a user defined interface perturbation is added to the steady state interface and the code starts to compute the transient evolution of the perturbation, recalculating the change occurring to the Lorentz force at each time step. Solving for the typical 4000 time steps requires between 8 to 12 CPU hours depending on the speed of the processor. Figure 13 presents the results obtained for the base case using 4.5 cm of ACD, 24 cm of metal pad thickness and CF = 0.02.

Considering the very low Bz, the quite reduced Jy and a relatively high ACD, the cell is predicted to be extremely stable at CF = 0.02 which is on the low side of the usual range of 0.01-0.05. An ACD squeeze test would be required to precisely adjust this parameter.

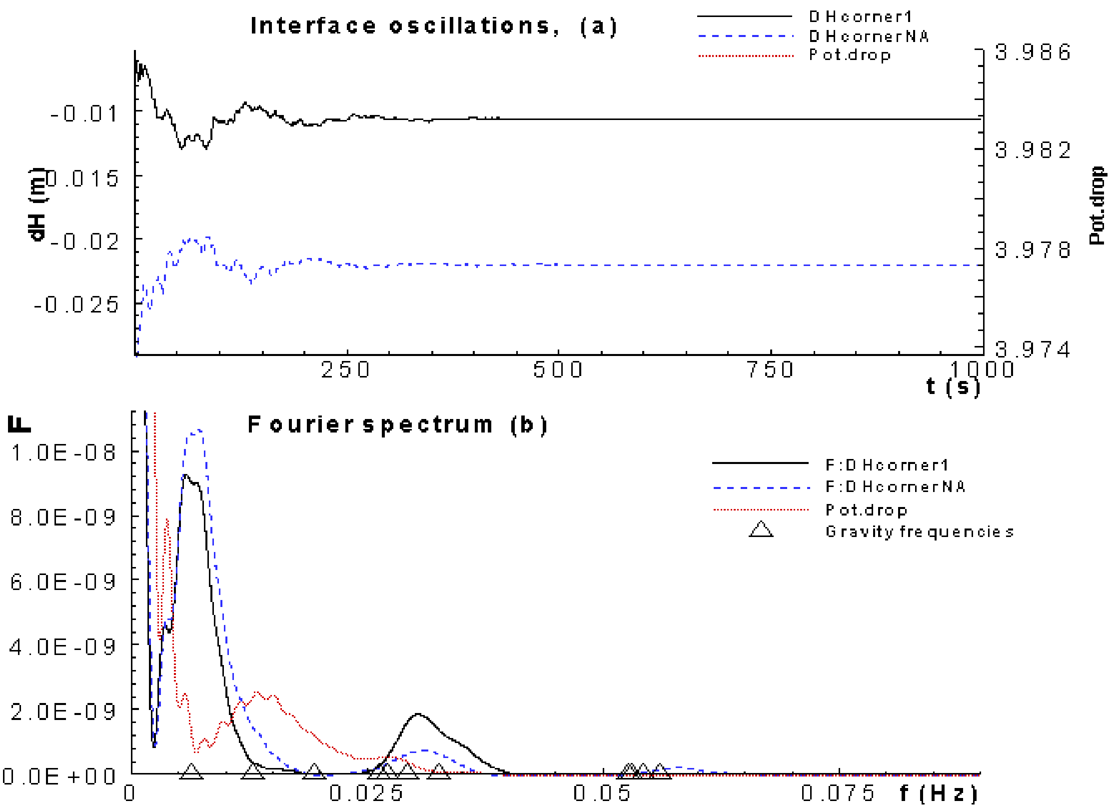

Figure 13. Results of MHD-Valdis transient cell stability analysis model for the retrofitted 330 kA cell operated at 350 kA.

9. Conclusions

The present work presents a model results comparison exercise for the specific case of the 330 kA SAMI retrofitted into a 350 kA cell. SAMI presented its own model results in a TMS 2024 paper [1]. SAMI used an ANSYS based magnetic model and an ANSYS based full cell slice thermo-electric model to retrofit the busbar network and the cathode assembly design.

The model results presented in this work are mostly produced by MHD-Valdis code but other results produced by ANSYS based models developed by GeniSim are also presented.

The vertical component of the magnetic field (Bz) calculated by MHD-Valdis shown in Figure 4 and the ANSYS calculated Bz presented in [1] are very comparable, so it was decided not to investigate for any cause of discrepancies. Many causes of discrepancies could exist: the details of the representation of the busbar network using 1D line elements, the details of the setup of the convection and radiation boundary conditions on the busbar, selection of the B-H curve for the calculation of the potshell magnetization, etc.

The 4 sets of results for the transversal horizontal component of the metal pad current density field (Jy) presented here and the Jy field presented in Figure 4 of [1] are also very comparable, so again it was decided not to investigate for any cause of discrepancies. Many causes of discrepancies could exist: the setup of the ledge profile and ledge toe, the setup on the contact resistance between the cast iron and the cathode carbon block, the setup of the temperature dependent materials electrical resistivity, the setup of the convection and radiation boundary conditions in the thermo-electric models or the choice of user defined temperatures in the electric models, etc.

Considering that the set of results produced by SAMI and the set of results produced by GeniSim have been obtained totally independently, without consultation and they are in very good agreement, this is a very good sign of model results reliability.

On the design side, according to the Figure 5 and Figure 7, we can see that the Jx is smaller than Jy, so it should have less influence on the cell stability. Hence, further reduction on Jy can be investigated using models that only compute Jy, but eventually when Jx and Jy get to same magnitude, then it will become important to use models that compute both, such as CurDen or MHD-Valdis.

The final conclusion is that this model comparison demonstrates that the MHD-Valdis code for electric, magnetic and CFD calculations is quite reliable and efficient.

10. References

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