Electromagnetic Modeling of Aluminium Electrolysis Cells Using Magnetic Vector Potential

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Abstract

This article presents the numerical simulation of the electromagnetic fields inside the aluminium electrolysis cell and its surroundings using the magnetic vector potential formulation. The finite element commercial code COMSOL was employed both for meshing and solving the numerical model.

Usually, in the previous works, scalar magnetic potential combined with Biot-Savart integration codes was used, often combining 1D and 3D finite elements. Magnetic scalar potential alone is not suitable for the electrolysis cell problem because internal currents are present. It must therefore interact with other codes to add magnetic field generated by free currents in the final magnetic field in an iterative process. Some works also used the integral method to account for the shell shielding combined with Biot-Savart law. The vector magnetic scalar potential however can complete the task in a single step, with the penalty of three times more degrees of freedom. Computational resources and codes have now reached the capacity to allow the use of the complete magnetic vector potential.

The model presented here is able to include the neighbouring lines, steel shell shielding, three dimensional busbars and electrodes, all fully modelled in 3D finite elements, which have to include the surrounding air. The amount of modelled air space necessary to correctly represent the magnetic field bias coming from neighbouring lines is discussed. The modelling results were compared with measurements made in operating cells and with previous magnetic scalar potential results obtained using other software.

Keywords: Aluminium electrolysis cell, magnetohydrodynamics, MHD, magnetic field simulation, magnetic vector potential.

1. Introduction

In aluminium electrolysis cells, the magnetohydrodynamic (MHD) features are determinant factors in the current efficiency and energy efficiency of the electrolysis process. The bath and the liquid aluminum form a system of two immiscible liquids inside the cell cavity. Both liquids are set in motion by the MHD forces (Lorentz forces) produced by magnetic fields coupled with the current densities inside the metal and the bath. If MHD forces in the liquids are too strong and/or asymmetric, the metal pad movement becomes faster, increasing the back-reaction rate and also increasing the risk of metal pad waves. Such undesired disturbances in the process may be controlled by increasing anode-cathode distance (ACD), thus increasing cell voltage and energy consumption. Principles of MHD design of aluminium reduction cells have been laid down in the literature [1] aiming the improvement of magnetic fields features resulting in better cell performance.

The magnetic fields found inside an electrolysis cell can be understood as a superposition of the effects of all conductors surrounding each cell and even the neighbour cell lines. Magnetic field

calculation can be very complex considering the hundreds of conductors, complex busbar geometry and also steel magnetization effect present in potshell, collector bars, anode yokes and superstructure also denominated “magnetic shielding effect”.

2. Evolution of Magnetic Field Calculation in Aluminum Electrolysis Cells

When the cell current and size increased in the 1960’s and 1970’s, it became clear that the MHD of the cell has to be understood and also considered when designing new cell technologies. From that period, one of first magnetic field models can be found [2], where the busbars are approximated as one-dimensional conductors and the shell magnetization effect was considered in the simulation by representing the steel as a collectivity of magnetic dipoles which produce magnetic shielding. This method was used in an in-house code to calculate the magnetic field of the cell for the input to ESTER-PHOENICS commercial code [3].

With development of more affordable computational capacity, models based on Finite Element Method (FEM) became available for electromagnetic field calculation. One approach was to use FEM for the electrical fields inside the studied cell parts combined with Biot-Savart Law integration for magnetic fields (from busbars, neighbouring cells and lines) and the integral equation method to account for steel magnetization. The main advantage of the integral equation method is that the surrounding air and other non-conducting permeable parts do not require to be meshed. This method was used in in-house codes to supply the magnetic field of the cell to ESTER PHOENICS commercial code [4 - 5]. It is also used in MHD-VALDIS [6 - 7].

In 1994, Dupuis and Tabsh [8] developed a procedure to compute magnetic fields in ANSYS. The steel parts and magnetization effects were then included in the FEM model, which required modelling the surrounding air of the cell. ANSYS usually offered four options to calculate magnetic fields:

- Reduced Scalar potential (RSP), solves 1 load step;
- Difference Scalar Potential (DSP) solves 2 load steps;
- Generalized Scalar Potential (GSP) solves 3 load steps;
- Vector potential (VP), solves 1 load step.

Strictly using FEM, the only option to calculate magnetic field in regions where internal currents are present would be the vector potential (VP). Dupuis and Tabsh [8] cited the difficulties in using FEM for the complete magnetic field calculation of the electrolysis cells. At that time, they considered not viable to use the vector potential available in ANSYS due to the following problems:

- All conductors of the studied cell, neighbouring cells and lines required solid 3D mesh. Meshing a large number of parts was considered a time-consuming job.
- Vector potential uses 3 degrees of freedom per node, producing very large finite element matrices, impossible to solve by computers available at that time.
- The amount of modelled air would also increase due to the necessity of enclosing all solid modelled busbars, further increasing the computational requirements.

All scalar potential approaches are suitable only for magnetic domains without electric currents. However, if the magnetic field generated by internal currents is introduced by a source term in each element, GSP [8] could be used for the final cell magnetic field calculation. In ANSYS, it was then possible to use electrical elements (LINK68, SOURCE 36, SOLID5) to calculate currents and afterwards perform a Biot-Savart integration for each element creating the source term of the scalar magnetic potential. The final solution would then be reached in 4 steps: Biot-Savart integration plus the 3 GSP steps. Since the development of the GSP magnetic field

7. References

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