Modelling Study of the Impact of Daily Power Modulation on Cell Thermal Balance

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Abstract

Over the last few decades, electric power consumption has increased faster than the increase in power generation. In parallel, the increase of volatile power generation exposes us to a variation in electricity supply, which contributes to driving the prices. Flexible power is a demand-driven power management strategy, based on cost and availability of energy, that has changed the aluminium cell production rate and power consumption dynamically. This can provide benefits for both the smelting industry and the power grid, particularly as intermittent renewable energy sources become more prevalent. However, power modulation raises challenges for preserving the stability and efficiency of the smelting process, which is susceptible to temporal variations of mass, thermal and electrical balances. It is complicated to follow bath temperature variations linked to current fluctuations, given that high variation can be the primary factor for heat imbalances in the cells. In this paper, we present a new approach to follow the cell behaviour in terms of thermal balance during power modulation.

A thermo-electrical 3D transient model is used to simulate scenarios with different inputs in order to estimate the impact of power modulation on the thermal fields as well as the energy balance in the cells. This model was tested in the Laboratoire de recherches des fabrications (LRF) prototype pots to assess its predictivity and response to energy variation compared to measurements. The simulation results, for a given amperage amplitude, show an accurate prediction of the cell temperatures across various locations, particularly in the bath, and also the ledge profile variations. Moreover, this modelling enables us to estimate the temperature evolution on the cathode block surface, which allows a precise view of the cathode thermal state.

Keywords: Aluminium electrolysis, Power modulation, Thermal balance prediction, Transient model.

1. Introduction

The aluminium electrolysis process requires several hundred of thousand amperes of electricity. The aluminium industry used about 8 % of the global industrial electrical supply in 2009 [1]. In parallel, Reuters quotes (IAI) projects that by 2030, there will be a nearly 40 % increase in global demand [2]. As the prevalence of intermittent renewable energy sources has risen, this has resulted in larger fluctuations in the price and availability of electricity [3]. This represents a challenge for the smelting industry to compromise between the energy sourcing problems and increasing production costs. Usually, aluminium smelting pots run at a steady power. The response to these confrontations, linked to increasing electricity prices and the limitation of power sources, is a power modulation approach. This flexible operation allows a compatibility between renewable energy and the electricity network, which can function as a smart grid. Power fluctuation works by overproducing when grid electricity demand is low to counteract lower production when demand is high.

The electrolysis cells can then be considered as "virtual batteries" by the electricity network. Thus, by modulating the amperage which passes through the pots according to the availability of energy on the grid, it is then possible to participate in smoothing energy consumption on the network, by optimizing aluminium production. In addition to the relative financial gains made by electrolysis plants, due to the optimization of production during off-peak periods, the common interest is also to avoid starting coal or gas power plants, to respond to peaks in demand on the network, which leads to generating high CO_2 emissions.

In past years, as early as in the 1990s, experiments related to power modulation were done in electrolysis cells in Brazil [4]. In addition, some studies were carried out where thermal and mass balance were considered in both steady and transient state [5], simulation analysis highlighted the ledge profile behaviour with manipulating some variables. Moreover, European smelters also carried out energy fluctuation tests without losing thermal control on the pots to keep heat balance and production in a stable state. To do this, retrofitting was done on a whole potline by including busbar enhancement and an addition of new heat exchangers mounted on the shell [6].

As already seen, during power modulation several aspects and physical phenomena must be carefully considered in order to ensure good control and a long lifespan of these electrolysis cells. These aspects include heat transfer, bath temperature, shell temperatures, pots thermal state and ledge profile. An increase or decrease in amperage over time, leads to a change in heat flow towards the pot sides, a variation in the bath temperature and in the liquidus temperature which influences the ledge formation [7]. The ledge is sensitive to thermal imbalance leading to melting or freezing and as a result a change in thermal and mass conditions will take place in the cell. This thermal imbalance must be anticipated and controlled before, during and after the power modulation, to maintain cell life duration and performance.

To consider these complex coupling phenomena, at Rio Tinto - LRF, we focused on the prediction of the bath temperature, and the cell thermal state during power modulation. The Flex Power project led on prototype pots allows a large set of data to be tested and analysed in order to see the capability of the thermo-electric 3D model to predict the pot thermal state.

2. Flex Power Project

The "Flex Power" program, conducted within Rio Tinto, aims to determine the possibilities of energy modulation for electrolysis plants. In other words, it is a question of determining which amperage modulation ranges are admissible by the electrolysis cells to identify necessary operational standards of operation to limit negative effect of modulations. Different 12 hours long amperage modulations are tested on prototype pots operating at 500 kA in steady-state mode. Fluctuations are about 4% from its average. Operations are done daily (change of anode, metal tapping), requiring adjustments to the resistance of the pot. These trials collect a large set of data so that it can be exploited and analysed for the need of the thermo-electric model.

2.1 Measurements Descriptions

Several thermocouples are placed on the pot side wall at different heights as shown in Figure 1. The thermocouples are linked to the Alpsys® system controlling the cell and provide real-time data [8]. The thermocouples are distributed both upstream and downstream. There are four levels of measurements aligned vertically.

difference of 2.4 °C. It is mentioned also that the slopes were well respected and no thermal deviation during the simulation was detected.

Secondly, measured and predicted shell temperatures show that no variation was linked to amperage modulation. A comparison of ambient temperatures and shell temperatures evolution confirmed the interdependence between them. So, by maintaining a non-variable ambient temperature, the model ensures a good thermal response.

After these predictions, the model is able to estimate the variation of the frozen ledge profile. The numerical calculation shows a variation of the ledge well consistent with the amperage fluctuation and the temperature variation by establishing a cyclical regime at the end.

Finally, the state of the cathode block was monitored under Ansys® which showed the temperature distribution in the normal interval during the modulations. In addition, this surface is monitored by calculating the fraction of this surface below the liquidus temperature. Likewise, the model showed a cyclical regime which responds well to modulations without divergence.

As conclusion, the 3D thermo-electrical model demonstrated its ability to estimate the thermal state of the modulation scenario carried out on the prototype pots. We have considered this test was done at LRF with a successful estimation.
The next steps will be to determine the robustness of this model by testing with others pot modulation scenarios.

Future works are already in progress on a simplified physical model that can give the estimations needed, for plants wishing to start power modulations, in few minutes. This model can be implemented in the aluminium smelters which give a real time state of the thermal behaviour of the potlines.

6. References

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