Paradigm Shift in the Indication of a Stable Cell during Power Modulation

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Abstract

A megatrend of the next decades is the energy transition from conventional power to renewable. Adapting the aluminium smelting process to a flexible power supply needs the rethinking of a number of aspects in the smelting process. Manipulating thermal and magnetic impacts associated with amperage changes are just a few of these aspects.

The core element of our Virtual Battery is our newly developed control system. Conventional pot control systems are designed for conventional operations and static process targets. This becomes obsolete or even contradictory when operating with power modulation. Hence we need a different approach.

The approach that is outlined here is divided into three areas. The first step is to reduce the energy input as far as possible and to compensate in a subsequent step the heat loss by heat exchangers. Each cell is subject to thermal and process engineering limits, which were intended for the cell at TRIMET Essen. If the minimum cell resistance and the min/max limits of the heat losses are well known, the regulation of the heat balance can be done by changing the resistance. According to Ohm's law the resistance can be adjusted to its minimum inversely proportionally to the current. After reaching the resistance minimum, the heat loss through the heat exchanger is increased in proportion to further current increases. Finally control systems of an existing process control must be adjusted so that it does not counteract the energy flexibility, but promote it. The limits and values, such as temperatures and their deviations, of operating a cell have to be modified and the meaning of a stable cell rethought.

Keywords: Aluminium reduction cell process control, virtual battery, energy demand management, renewable energy, real-time heat balance control, energy counter.

1. History of Power Modulation

The idea of current modulation using aluminum electrolysis cells is not new; as early as in the 1990s, experiments were carried out in electrolysis cells in Brazil [1, 2]. Load management was also already an issue in 1974 in the electrolysis in Essen. Alusuisse engineers [3, 4] made various calculations for power reduction. Their ideas, however, mainly involved turning off pots rather than modulating them with the help of amperage. The innovation of load management nowadays is that over a certain period of time production volume and thus performance are kept constant. The modulation takes place for only a short time and above all with a faster change. This development was accelerated by the addition of renewable energies to the grid and therefore changed the time of the generation of electricity tremendously. Figure 1 shows the production and consumption profile predicted for the year 2050, showing the deficit in red and the surplus in green.

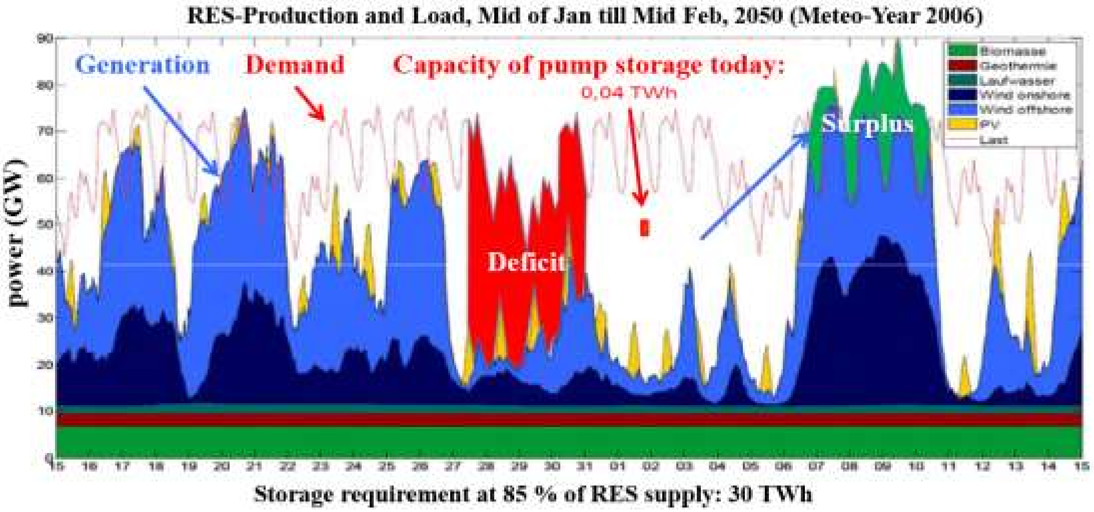

Figure 1. Production and consumption profile for the year 2050 [5].

The novel mode of modulation has negative effects on the process efficiency, which is designed for a stable energy balance. The essential point is to find out when the efficiency drops sharply and to optimize the process to further delay this point in time. The core of the new mode of production is to interpret the old philosophy correctly. The cell needs a consistent energy balance and not a constant energy input. Ultimately, economic consideration is once again a decision maker between gaining modulation revenue and losing process efficiency.

2. Theory of Side Ledge Changes

The change of the heat loss during the modulation over the period t corresponds to the changed enthalpy of the cell. This can be stated at time t as follows [6]:

$$\Delta \dot{Q}_I = m c_p \frac{dT}{dt} \tag{1}$$

where:

$\Delta \dot{Q}_I$ Heat flow rate, W
m Mass, kg
c_p Specific heat capacity, J kg^{-1} K^{-1}
T Temperature, K
t Time, s

It is advantageous that the predominant heat generation takes place mainly in the electrolyte itself, so that the enthalpy change is mainly noticeable here. Responsible for this are the massive movements of the electrolyte due to gas bubbles and magnetic field, as well as the very good thermal conductivity of aluminum (k = 100 W/mK) and electrolyte (k = 0.8 W/mK) [7]. The changed heat generation at anode and cathode contributes to this by the direct contact to electrolyte and aluminum. Thus, the enthalpy change of the liquid electrolyte is equivalent to the enthalpy change of the pot [8].

$$m_{bath} c_{p,bath} \frac{dT_{bath}}{dt} = m_{pot} c_{p,pot} \frac{dT_{pot}}{dt} \tag{2}$$

This approach is only valid until the adjacent areas respond to the heat loss change. Above all, the anodes and the edge crust, over which the majority of the heat is lost and which are the fastest to respond to the change. Due to its very good insulation, the heat loss across the bottom (hardware + software), to visualization (software). The foundation for this project has been laid and TRIMET is ready to embark on this paradigm shift in aluminum production.

8. References

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