Light Metals 2011 *Edited by: Stephen J. Lindsay*
TMS (The Minerals, Metals & Materials Society), 2011

New approaches to power modulation at TRIMET Hamburg

Till Reek[1]
[1] TRIMET ALUMINIUM AG, Niederlassung Hamburg, Aluminiumstrasse, 21129 Hamburg, Germany

Keywords: Power modulation, Energy price, energy models, side ledge measurements

Abstract

TRIMET ALUMINIUM AG acquired the Reynolds cell technology P19 smelter in Hamburg in 2006 after a complete shutdown. The 135 ktpa smelter was restarted successfully in 2007 and has been in continuous operation since.

The increasing spread of the energy price during night and day time, as well as long term price difference have lead to novel approaches to decrease the average energy price by operating the smelter with non linear energy input. Theoretical calculations were done to estimate the maximum energy difference of various cell states. Experiences were made of the impact on performance vs. modulation range.

This paper presents the theoretical background as well as practical data of a smelter operating with power modulation.

Introduction

TRIMET acquired the facilities of the Hamburg smelter in November 2006. The plant was shut down by the end of 2005 by the former owner HAW. TRIMET restarted the plant in fast order, operating at full capacity of 270 pots at 175 kA at Christmas 2007. In 2008 operation was very smooth; however an increasing power price as well as a huge spread of prices over the day presented an incentive to operate at non continuous current. For the 2nd half of 2008, all potlines were operated with power modulation.

Due to the economic crisis in 2009, production was cut to 50%. During that time, modulation was stopped as energy prices had leveled out at a comparatively low level. In expectation of increasing energy prices and increasing price spreads, work continued to set up all systems for power modulation. After restarting to full capacity at the end of 2009 and early 2010, modulation was restarted in one potline to continue optimizing procedures.

Incentives for power modulation

Customarily, aluminium smelters are built in locations where there is constant and moderately priced electrical energy available. As electrical energy is the largest part of the production cost, such a development is unsurprising.

Following this strategy, aluminium smelters were built in central Europe in the early 70s. When the first oil crisis struck in the mid 70s, construction was stopped and expansions curtailed.

With increasing energy prices and increasing energy demand in Germany since then, several smelters were closed down over the past 10 to 15 years. The remaining ones are facing an increase in energy price, which is pushing them to the brink of profitability, especially as they have to compete with modern, large scale green field projects as they are constructed in the Middle East or Asia. The only advantage older smelters have is that their construction cost is already amortized and they don't have to pay capital costs for the initial investment.

Due to liberalization of the energy market in Europe, it is virtually impossible to realize energy tariffs that are comparable to most of the other production location for aluminium in the world.

In addition, in Germany several taxes and levies were introduced to advocate renewable energies, resulting directly in a distortion of competition [1]. Due to the effect, that most of the renewable energies are non-base load suppliers of electricity – such as wind or solar power – the prices are also affected by the actual generation of renewable energy.

The availability of wind energy is highly inconsistent and – unfortunately – not related to the actual demand. Figure 1 illustrates the variability of energy from wind generation. In 2006 in peak times up to 16,000 MW was generated from wind in Germany, however, most often the energy amount generated did not surpass 1,000 MW.

This reflects directly onto the actual energy prices as power suppliers have to keep spare capacity to be able to still deliver energy on demanded, independent of the availability of wind or solar energy.

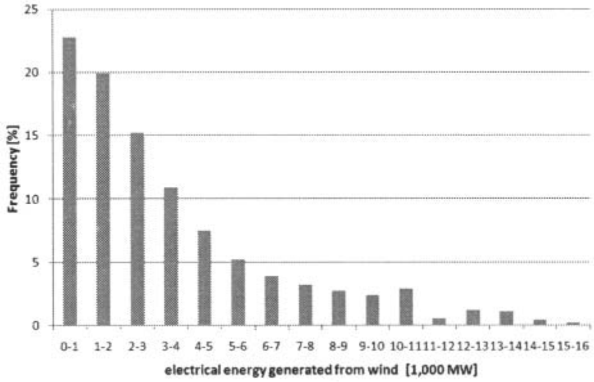

Figure 1: Degree of utilization of installed wind energy generating power in 2006 [2].

In addition, with a trading platform as the European Energy Exchange (EEX) which was formed in 2002, prices tend to reflect the generation cost of the last MWh instead of a market average.

Since the founding, energy is traded for each individual hour of the day, fixing a price between a fixed generation capacity and a variable energy demand. As energy demand peaks during daytime, prices increase for these hours as well.

Figure 2 shows the average energy price per hour in June 2008. Price varied from 40 €/MWh during night time to 150 €/MWh during midday on average. The peak price in that month was 213.08 € on June 25th between 11:00 and 12:00 am [4].

Even considering aluminium prices listed at the LME between 2,900 US$ and 3,100 US$ for this month, producing aluminum when the energy price is repeatedly above 100 €/MWh or 155 US$/MWh is not feasible.

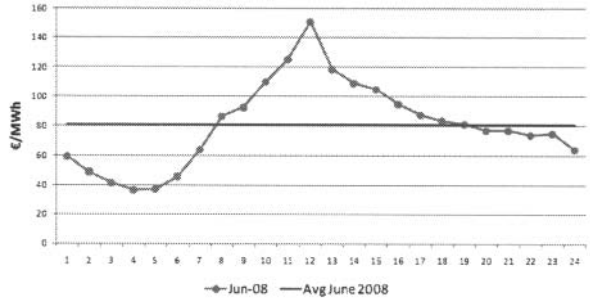

Figure 2: Average energy price variation in June 2008 as listed on the EEX[4]

Scope of power modulation

Due to the incentives presented earlier, some smelters have to adopt a strategy to cope with power modulation in order to remain profitable. Even though most of the industry still tries to operate with a current as constant as possible, there are incidents which indicate that a certain degree of modulation to the power input is in fact the norm.

For example, line amperage drops if there in an anode effect on the line. Depending of the length and cell voltage of the anode effect, the decrease of line current can exceed 10 kA and last for several minutes.

This happens routinely and it is not known to have a negative impact on the rest of the pot line.

The most severe case of power modulation is the line shutdown to cut out a cell for relining or to cut a cell back in line. Measures are taken to reduce the time needed for that operation, but a shutdown of a line for 10 to 15 min is quiete common.

It might be a stretch to call this power modulation. However applied differently, it very well falls into this exact field. It is common practice in Germany that in times of grid instabilities, the grid operators, after consulting with the smelter management, may throw the smelter off the grid as a substitution for cutting in a peak load power plant to stabilize the electrical grid.

Also, over the past years, a practice called peak shaving as been used repeatedly. This is practiced mainly during summer, when energy demand around midday peaks and prices at the EEX soar as well. In consultation with the grid operators, the smelters cut out one or several lines to reduce their electricity uptake for one hour. The energy is sold back to the grid operates. Smelters have been able to generate a profit of several tens of thousands Euros on each occasion.

Looking at the cell side of power modulation, it is a well know fact, that cells can attain different energy states due to various process conditions. The control of a cell always work to keep the cell within a very limited range of bath temperature und composition. In some instances, the control even works towards a set, single value temperature. However, looking at publications over the last years, there is no general agreement on the optimum temperature. Typically, the target temperatures in the range of 955 to970 °C are cited [5], depending on cell technology, process control and operating philosophy. If the bath is lithium modified, temperatures as low as 945 °C are quoted. The general agreement is that cells perform optimum in that range and efficiency decreases if you operate at bath temperatures considerably below or above.

The aim of process control is to drive the cells back into their respective target range and keep them there. With increased effectiveness of process control, the distribution of cell states – represented as bath temperature – has narrowed, leading to a better operation [3]. Relating a smaller variability of cell states to an actual range for optimum target bath temperature, results in a variance of cell states that still leads to optimum performance.

	Material	**Amount [kg]**	**Temp. [°C]**	**Energy contained [kWh]**
Anode	C	13,230	850	4,438
Cathode	C	14,000	935	5,282
Ramming paste	C	7,500	935	2,829
Collector bars	Fe	12,400	750	1,603
Side ledge	Na_3AlF_6	5,000	890	1,623
Metal pad	Al	8,500	955	3,344
Bath		***6,000***		
Cryolite	Na_3AlF_6	4,860	955	2,467
Al_2O_3		150	955	88
AlF_3		690	955	408
CaF_2		300	955	129
Sum				***22,210***

Table 1: Temperatures and amount of materials contained in a cell at 955°C

	Material	**Amount [kg]**	**Temp.[°C]**	**Energy contained [kWh]**
Anode	C	13,230	860	4,507
Cathode	C	14,000	955	5,467
Ramming paste	C	7,500	955	2,928
Collector bars	Fe	12,400	850	2,236
Side ledge	Na_3AlF_6	2,375	920	793
Metal Pad	Al	8,500	975	3,399
Bath		***8,625***		
Cryolite	Na_3AlF_6	7,485	975	3,877
Al_2O_3		150	975	89
AlF_3		690	975	413
CaF_2		300	975	131
Sum				***23,841***

Table 2: Temperatures and amount of materials contained in a cell at 975°C

If accepting temperature swings between 955 °C and 975 °C, assumptions can be made to the energy differences between these cell states. Table 1 and Table 2 state different temperatures for various materials located in the cell as well as the energy needed to heat the material to the given temperature and – if applicable – melt it.

Temperatures for certain materials are a collection of cell investigations, such as bath and metal inventory determinations, temperature gradient measurements in the cathode lining, cell construction data and extrapolation. To simplify the calculation, materials which have a definite temperature gradient – such as current collector bars, anodes and cathodes – are still treated as having a average, uniform temperature. Care is taken for the

collector bars to avoid temperature swings beyond recrystallisation temperature.
Absolute temperatures are not as important as the temperature variation between the different states.

The change in liquid bath mass is the result of the melting of side ledge. In this scenario, the AlF_3-content dropped from 13 % to 8 %, which is a common occurrence for the stated temperature change.
Figure 3 shows the contained energy graphically. The major contribution to storing energy is from melting side ledge and increasing the liquid bath mass during the high energy period. It highlights, that cells operated on power modulation are very susceptible to hot or red side walls. If the cell has been driven to maximum amperage, this danger is increased manifold. Due to constrains mainly in the anode bake furnace and also in anodic current density, the TRIMET Hamburg P19 cell is operated with a wide side channel and sufficient side ledge.

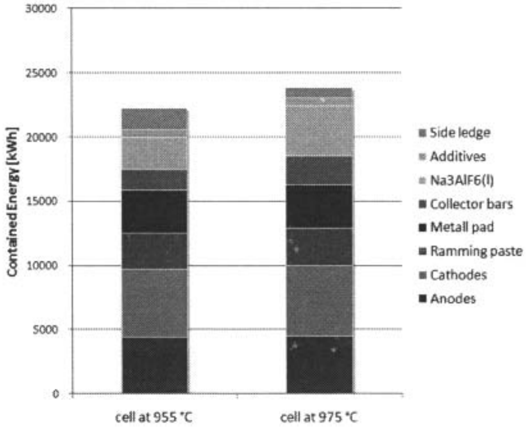

Figure 3: Comparison of two different energy states of a reduction cell

For the cell as it is installed in Hamburg, a theoretical limit of 1.6 MWh was calculated for the energy difference that can be stored in the cell.
Power modulation should aim for two goals:

1. The average power introduced into the cell shall average to an energy input that is similar to the energy input with which the cell was operated previously on continuous amperage. This should keep both, energy needed for metal production as well as heat loss in mind.
2. The maximum deviation from continuous power input shall not exceed the theoretical maximum.

The assumption is that your process efficiency will decrease significantly if you exceed these boundaries. In 2008 TRIMET Hamburg operated on a modulation scheme that was significantly below nominal energy input. During this time, significant losses in current efficiency where recorded.
Not all cells can be operated at exactly that temperature swing, but are scattered close to an average. Thus efficiency will decrease significantly as one approaches or exceeds this limit as an increasing fraction of cells is beyond .the optimum control range.

Trails

Using the data from the delta energy calculation, a model was set up to calculate the energy demand of the cell operating over a range of amperages. This model assumed a constant heat loss as a first step on simplification. The model includes variables for the flowing cell parameters:

- Line amperage
- Cell resistance
- Alumina addition
- Anode consumption
- Parameters related to anode change
- Heat loss through off gas

With this model, modulation schemes were set up to stay within the parameters defined previously, namely, aiming for a midterm energy balance that is similar to the one the cell operated at continuously. In anticipation of the effect of the modulation on efficiency, only a fraction of the calculated theoretical energy difference was reached.
The cell was operated keeping the resistance set point constant, aiming for an unchanged anode cathode distance. However, due to cooling effects during the modulation cycle ACD was effectively squeezed. This method is the most severe with regards to cell condition; however, it is also the most effective to reduce absolute energy consumption for the reduction line.

The first scheme was then put into operation on one reduction line, keeping the second line operating at constant amperage as a reference for general performance. As both lines are supplied with the same alumina as well as the same anodes, both featuring the same pot design and operating practice, the difference in performance can be attributed to power modulation.

The modulation scheme was designed to have a maximum energy difference of 490 kWh, or roughly 30 % of the theoretical value. The scheme consisted of increasing the current up to 185 kA during night time. To release this energy during the daytime the current was lowered to 160 kA for 4 hours.
To avoid negative impact of excessive cooling, as was experienced during the modulation in 2008, the scheme operated at a slightly increased energy input compared to stable operation.

The line operated at this modulation strategy for 2 month. To be able to evaluate the performance after only 2 month, several cells were set up as reference pots. Measurements were done to evaluate the cells in detail. To ensure that production figures are indeed representing the actual cell performance, metal inventory test were made and the cells were tapped separately for the whole period. It was proven that the cell performance corresponded to reduction line performance with regards to current efficiency and energy consumption. No impact of this modulation scheme on reduction line efficiency was found.

Bath inventory changes and side ledge measurements

Side ledge measurements were done on selected test cells during the modulation. There are several reasons for measuring the thickness of the side ledge during different energy states.
Firstly, the measurement was used to validate the change of bath inventory during the modulation. Secondly, it was used to check if there is a change in the shape of the side ledge, e.g., moving from side ledge to bottom freeze or similar. Lastly, during the high

energy phase, there is little side ledge left. If there are one or more problem spots where the side ledge melts first, exposing the underlying SiC bricks, a serious impact on cell life is expectable.

For measuring side ledge thickness, a device was used that lowers a turnable hook into the bath. The hook is turned until it touches the side ledge on the inside of the cell. By measuring the angle by which the hook can be turned until it touches solid ledge, the thickness of the side ledge can be calculated. The hook is lower in 50 mm steps to measure the thickness over the whole height of the liquid phases. Measurements points were taken in front of all 18 anodes. The device is reverenced to the outer edge of the deck plate. Figure 4 shows the measuring device in detail.

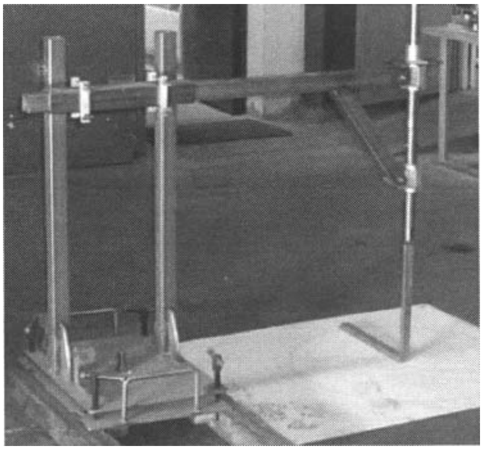

Figure 4: Measuring device for measuring side ledge

Measurements were done on test cells at the beginning and at the end of the period, during which the line operated with modulation. During two months of operation with power modulation, a trend of decreasing side ledge thickness in the metal pad was found. This was attributed to the slightly higher energy input than during continuous operation. At the end of the modulation period, the thickness of side ledge was still within acceptable limits.

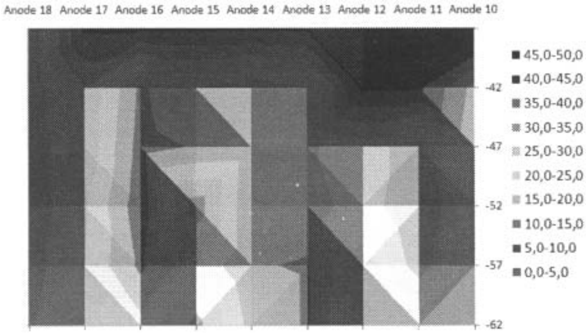

Figure 5: Side ledge profile of the downstream side of cell 331 after the low energy period

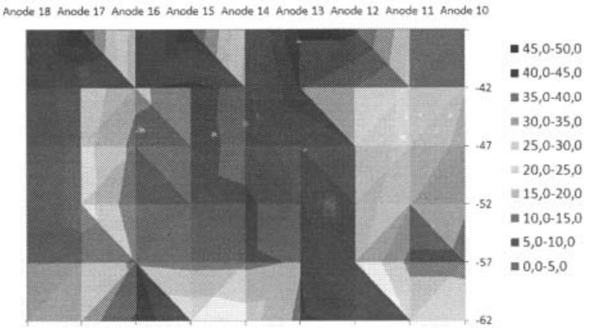

Figure 6: Side ledge profile of the downstream side of cell 331 after the high energy period

Changes in side ledge thickness were found to be more pronounced on the downstream side of the cell. In general, the side ledge was thinner here as well. This is in agreement with the flow patterns within the cell.

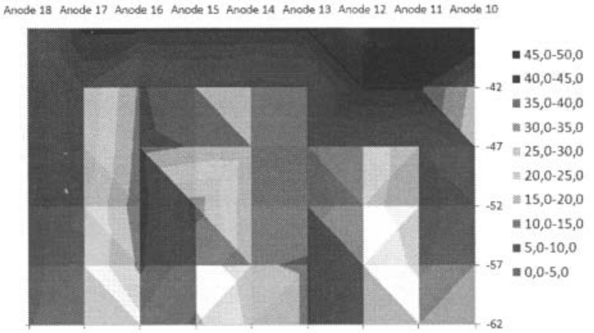

Figure 5 and Figure 6 show the thickness of the side ledge from the cathode surface upwards. As can be seen by the rather high values in general, the cell operates with a substantial side channel, enabling a thick side ledge that can be used for power modulation. On average, the cell melted 5 cm of side ledge moving through a 24h modulation cycle with a neutral energy balance. Assuming that a similar amount of side ledge melted on the short sides of the cell, this amounts to close to 2 tons of material. To melt this much, 315 kWh are necessary. 64 % of the energy introduced during the high energy period was used to melt side ledge. This is a significantly higher percentage than was estimated in the theoretical energy difference.

Bath inventory tests were also done, but they were not conclusive. The time delay between the addition of tracer material and the final sampling proofed to be too long to result in a bath inventory that corresponds with the energy state of the cell.

Results and future work

A test campaign was conducted at TRIMET Hamburg, operating one reduction line with a power modulation ranging from 160 kA to 185 kA. The maximum energy difference stored in the cell amounted to 490 kWh. This is about 30 % of the theoretical energy difference that a cell of this type can hold. It was found that with this modulation, there was no effect on current efficiency, compared to a second line of the same pot type operated on the same site.

With side ledge measurements a substantial change in bath volume was proven. No critical spots were found where the side ledge had molten completely.
However, the change in ledge thickness was higher than anticipated. Further tests with different modulation schemes will be conducted to investigate the correlation between power modulation and melting and freezing of side ledge.

Also, all models used assume a constant heat loss during power modulation. Exemplary heat flux measurements and off gas temperatures show that this is evidently not true. Due to the melting and freezing of side ledge and top crust, heat flux and heat loss change. This has to be incorporated into models tracking the energy state of the cell.
To increase the range of power modulation beyond what is currently possible, further steps have to be taken that allow a modulation of the heat loss directly. For the heat loss through the off gas tests will be conducted to vary the suction rate of the dry scrubber. For the heat loss through the side wall, installations that regulate the air flow along the side wall have to be designed and tested.

References

[1] Kruse, H.; German power market - Final countdown for the aluminium smelters, proceedings 8th Austalasian Aluminium smelting conference 2004
[2] Pieper, T.; Fleckenstein, H.; Rosen, M.; Das Wohl und Wehe des Windes, EMW, Release 01-2007
[3] Iffert, M.; Rieck, T.; White, P.; Rodrigo, R., Kelchtermans, R; Increased current efficiency and reduced energy consumption at the TRIMET Essen smelter using 9 Box Matrix Control; Light Metals 2003
[4] www.eex.com
[5] Utigard, T.A.; Why best pots operate between 955 and 970 °C; Light Metals 1999