Transformation of a potline from conventional to a full flexible production unit

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Abstract

A trend for the next decades is the transition of aluminium electrolysis potlines from a stable energy supply to a highly volatile energy input, which is driven primarily by the increased usage of renewable energy sources on the power grid. Adapting the aluminium electrolysis process to a flexible power supply needs rethinking on a number of aspects affected by unpredictive power changes. Manipulating thermal and magnetic impacts associated with fluctuating amperage are just a few of these aspects, however main topic of this paper.

Installing heat exchangers and magnetic field compensation in a potline while at the same time operating it, is a major challenge. Bringing the heat balance and production into a stable state, during massive power outages, while upgrading busbars design and insulating with heat exchangers in a safe routine, was the main challenge to handle.

The transformation process of a potline while maintaining stability also required great cooperation between contractors and employees.

Background potline retrofitting

Hall-Héroult production potlines characterize themselves as “slow movers”. Main drivers for progressing slowly are the large capital costs involved in building new potlines, safety issues within retrofitting existing potlines as operation continues while changes occur. For the latter, endurement of loss of performance is also a factor to take into account. However, retrofitting an old potline may be a good alternative to a complete shutdown as the potline remains cost effective and profitable. Changing existing potlines can be done in various ways, as described in this paper. New technology that has been applied to retrofit old potlines are for example [10]: point feeder technology, cathode design improvement, anode design improvement, busbar design for improved magnetic field compensation and automation of pot controllers.

As a trial, TRIMET Essen took on the challenge to retrofit a whole potline, which is capable of handling energy fluctuations without loosing thermal control of the cells and compromising safety of contractors working in the potline. Before retrofitting a whole potline, a study was conducted on a special group of retrofitted cells. The retrofitting included busbars enhancement and new shell heat exchangers (SHE) mounted on the sidewalls of the shell.

Trial on booster group

As a first trial, modifications were installed on a mid-line booster group of 12 pots, with capability of increasing current by up to 25kA above the rest of the potline. However, the current of the booster section cannot be reduced independently below the base line current without reducing current on the rest of the pots in the line, which is not possible in a safe manner for more than short periods. For this reason, most trials have involved upwards modulation from the base line current and downwards modulations, starting from an elevated state down to the base line current. Some trials have involved reducing the whole line current for up to two days, with additional voltage applied to non-SHE pots. [8]

Future at TRIMET

<u>Renewables / Flexibility</u>

The idea of current modulation using aluminum electrolysis cells is not new; as early as in the 1990's, 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 faster amperage changes. This development was accelerated by the addition of renewable energies to the grid and therefore changed the time of the generation of electricity tremendously. **Erreur ! Source du renvoi introuvable.** shows the production and consumption profile predicted for the year 2050, showing the deficit in red and the surplus in green.

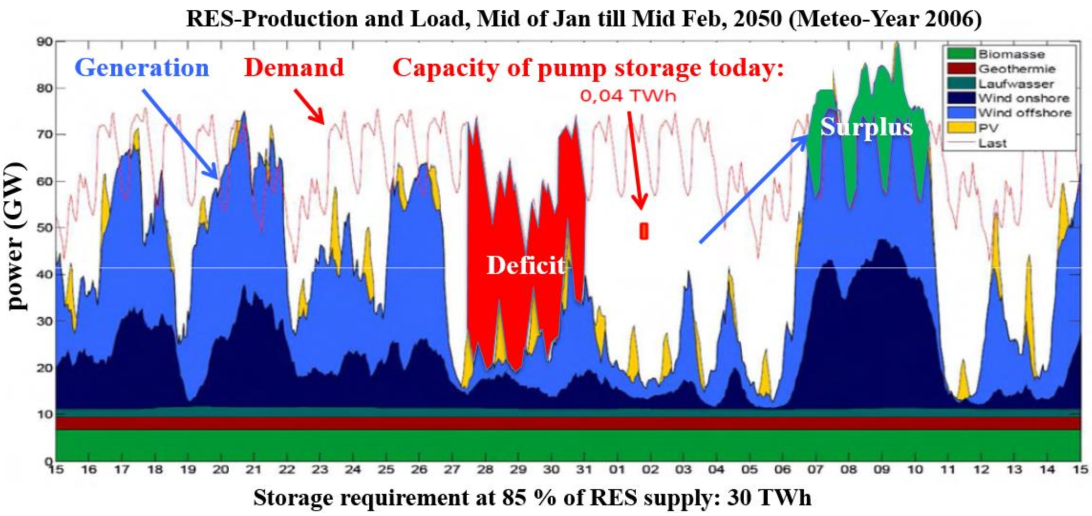


Figure 1: Production and consumption profile for the year 2050 [5]

<u>Magnetic Compensation</u>

Cells at TRIMET Essen are end-to-end cells with one riser on both upstream and downstream sides and have an asymmetrical busbars system designed in the late 1960's. As can be seen in Figure 5 the metal heave at 162kA is considerably high. Increasing/decreasing amperage would increase/decrease the metal heave and generate control problems. In order to improve the magneto-hydrodynamic (MHD) cell stability for increasing the operation flexibility the busbars have been upgraded. In April 2014, a number of cells were measured by KAN-NAK and a 3D model of the existing cell was built based on:

the operating parameters, the lining and busbars design (see Figure 2). The existing cell was computed using MONA software [6].

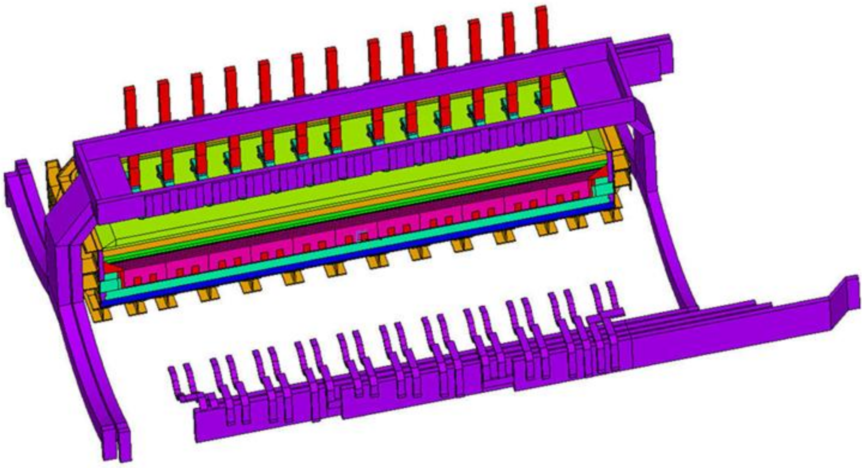


Figure 2: 3D model of existing cell

A number of alternative topologies and current distributions were modeled and computed. The model included a 3D model of the studied cell, a 3D filiform model of the busbars and of the neighboring cells and a 1D filiform model of the neighboring lines. For each scenario, the MHD stationary state and the MHD stability were computed. The objective was to minimize the growth factor of the oscillation modes of the metal pad at 162kA and 185kA (at constant internal heat generation) or in other words to make the cell more robust against MHD instabilities.

An optimized busbars topology and current distribution has been obtained. The main changes are the increased current in the downstream riser and the T busbar below the cell. The maximum growth factor for the existing and optimized busbars is shown in Figure 4Figure 3 as a function of line current. The maximum growth factor at 185kA with the optimized busbars is lower than at 162kA with the existing busbars.

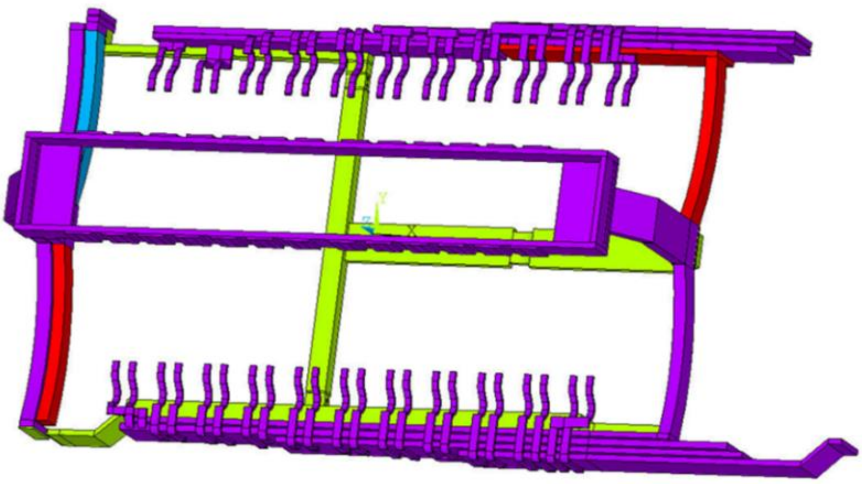


Figure 3: Optimized busbars with existing busbars in violet, new busbars in green, modified busbars in blue and disconnected or used for shortcut busbars in red

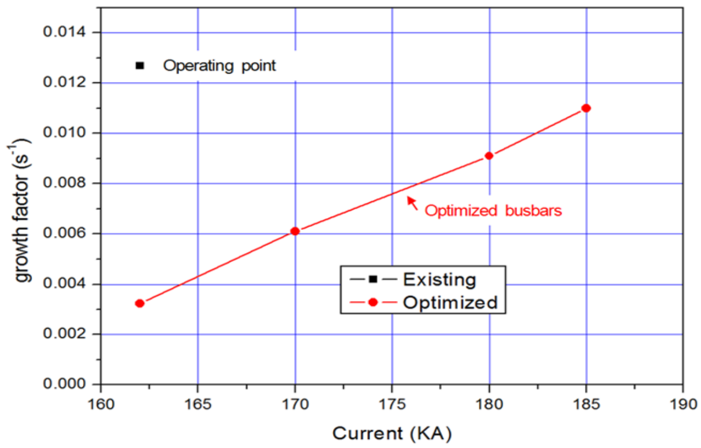
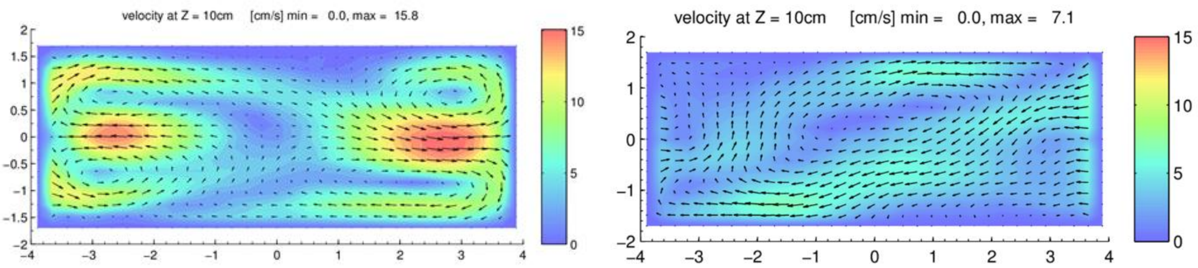
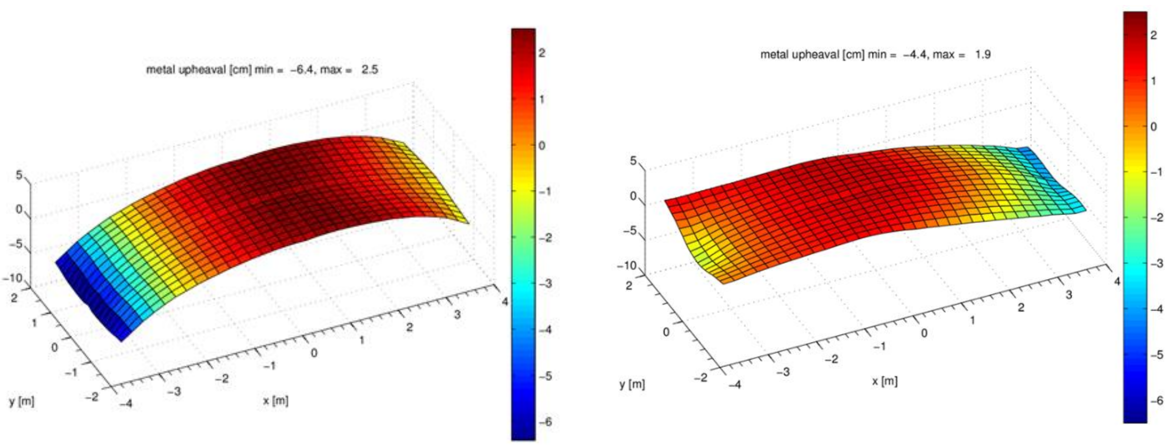


Figure 4: Maximum growth factor for the existing and optimized busbars as a function of line current (at constant internal heat generation)

By performing thermal-electric analyses with the MONA software, a basic engineering solution was found (see Figure 3). Additional busbars represented 5 tons of metal to be compared to the 20 tons of the existing busbars. With the optimized busbars, the external resistance is decreased from 2.22 to 1.95µΩ which represents an immediate specific energy saving of 0.15kWh/kg. The calculations also predict the impact of the optimized busbars on the velocity field of the liquid metal and on the shape of the metal-bath interface as shown in Figure 5. The maximum metal velocity is reduced from 15.8 to 5.8cm/s at 162kA and to 7.1cm/s at 185kA. The metal upheaval is decreased from 8.9 to 4.7cm at 162kA and to 6.3cm at 185kA. A low metal upheaval is of particular interest in the perspective of fast current changes in the line since the anode shape needs time to adjust to the new metal-bath interface.



Existing busbars at 162kA, v_{max} = 15.8cm/s *Optimized busbars at 185kA, v_{max} = 7.1cm/s*



Existing busbars at 162kA, upheaval = 8.9cm *Optimized busbars at 185kA, upheaval = 6.3cm*

Figure 5: Metal velocity field and metal-bath interface

The detailed engineering and the installation of the optimized busbars was done in two steps. Between June 2015 and March 2016, 16 cells were installed online with optimized busbars out of which 12 are in a booster section. In April 2018, the modification of the rest of the cells started with some modifications to the detailed engineering and to the online installation procedure, which was completed by August 2018.

<u>Shell heat exchangers</u>

The purpose of the SHE-technology is to allow dynamic control of the sidewall heat loss to help maintain operable heat balance when there are significant changes in the pot power input. This is achieved by varying the airflow through the individual exchanger units (controlled via a suction fan) to control the heat transfer rate at the sidewall as per the schematic diagram in Figure 6. Airflow above a base demand allows the sidewall heat loss to be increased, which compensates for power increase (eg. upwards modulation) in the pot. Operating with an associated airflow below the base demand reduces the heat loss thereby creating an insulating system that compensates for power decrease in the pot (eg. downwards modulation) [7, 8]. Figure 6 shows the variation in heat extraction achievable with varying flow rates through the system [9].

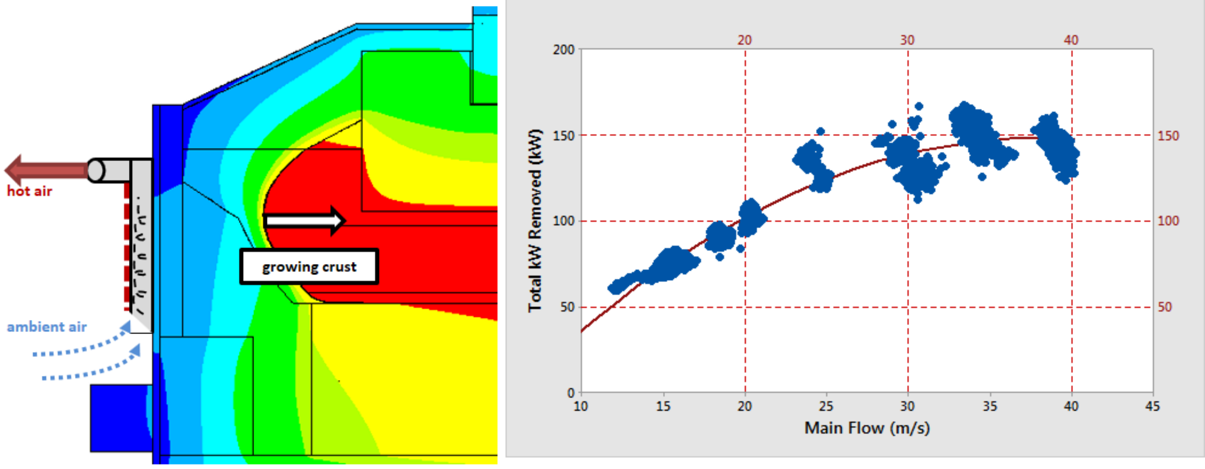


Figure 6: Schematic of Shell Heat Exchanger (SHE) Concept and the heat extraction from the booster group [6]

Problems faced and their solutions

Retrofitting a potline whilst at the same time keeping the production and process optimal is quite a challenge. The production time that got lost resulted in a lower amount of metal produced and backlog in operational tasks. The cells needed time to recover, which meant measurements made to check the condition of cells at the right time.

<u>Line time reduction over 6 month</u>

For implementing magnetig field compensation the busbar system needs to be reconfigured and welded, which can only be done when the line current is dropped. Therefor to implement magnetic field compensation on all remaining 108 cells, the potline needed three times a week power outages of 3 hours, which is equal to running only 95% of the time on full power. Or in other words in average less then 23 hours per day over 6 months.

Table 1: Timestamp of power outages

Day	Timestamp
Monday	7:30am-09:00am 12:00pm-13:30pm
Wednesday	7:30am-09:00am 12:00pm-13:30pm
Friday	7:30am-09:00am 12:00pm-13:30pm

<u>Work practice arrangements</u>

During the installation process of shell heat exchangers, no anode change, tapping or any other operation like measurements were allowed in areas where people were working in the basement. Figure 7 shows two pictures of the installation process:one of welding new flexes to the busbar system and one showing the piping for the heat exchangers in the basement. For safety reasons all cell operations had to be made during the night shift.

Figure 7: Basement activities implementing piping for the shell heat exchangers

In particular, this meant that work was moved between the shifts and potlines. For example, if in the installation area anode changes had to be made. The night shift already changed the anodes in that area and left anodes unchanged in another potline. The morning shifts then changed the anodes from the night shift in the other potline. All measurements for temperatures or chemistry in that area were made immediately at the beginning of the morning shift from 6am until 7am (start of the installation process). Furthermore, tapping, anode covering, maintenance work or crust breaking for anode change was organized in a similar manner.

<u>Heat balance recovery</u>

After a few hours of line current outage, a potline needs time to recover from cooling. This is usually done by increasing the cell voltage prior and after the planned power outages. The key factor we found was to plan the outages in such a manner that the cooling and heating were in balance. To recover from these many power outages, the decision was made to combine voltage with increase in line current.

Two approaches were investigated to determine the amount of voltage and line-current to add.

- A simple approach based on the calculation of internal heat generation, assuming that the cell heat losses are the same before and during the power cut.
- The second approach uses the cell simulator CellSim, which was already used for the power modulation study for ESSEN and accounts for the variations in bath temperature and composition, ledge thickness, current efficiency and mass balance.

The first approach predicts that two 1.5 hours power cuts can be compensated with +3 kA and +200 mV during aprox. 25 hours. Using CellSim the same power cut can be compensated +3.5 kA and +60 mV during 7.5 hours before the 1st power cut, 3 hours between the two power cuts and 10.5 hours after the 2nd power cut (21 hours in total at increased power). Be aware that the cell voltage after an outage is in average at about +200mV for 2 hours before returning to its operating state. Thus the average addition in the second approach is in average at about +90mV for 21 hours.

Table 2: Simple approach of achieving heat recovery

Potline Data		Simple Approach	
161.5 kA	Line Amperage	164.5kA	New Line Amperage
4.32 V	Potvoltage	4.52 V	New Potvoltage
0.36 V	External Voltage Drop	0.367 V	External Voltage Drop
2.02 V	Production Voltage	2.02 V	Production Voltage
313.3kW	Heat loss = 162 kA x (4.32-2.02-0.36) V	350.9kW	New heat loss
		37.6 kW	Difference
939.9kWh	Total heat loss over 3h	25h	Needed time to compensate

During the power cuts, the heat losses are lower than the ones at normal operation due to higher thermal resistance of the anodes (no current), lower gas emissions, back reaction and zero metal and bath velocity, the latter two being not accounted for by CellSim. Moreover, during, between and after the power cuts (until normalization), the heat losses are lower due to thicker ledge.

This explains why CellSim predicts a normalization of 21 hours at much lower voltage instead of 24.6 hours at constant heat losses. After the first outages we noticed, that the cooling down during the power cuts are even smaller since some effects are not accounted for by CellSim. Finally, we ended up with only +30mV (average +65mV) increase as some heat was also retained due to lower current efficiency and higher noise.

Increasing the power before the 1st power cut, even though being less efficient (due to thinner ledge), prevents a too low minimum bath temperature and shortens the recovery time between the two power cuts. The time between the two power cuts could be more than 5 hours, however that was not possible for the size of the welding team onsite.

Table 3: Voltage that was added to compensate for the energy loss

Day	Time	Voltage adder
Monday	12am-12pm	+30mV
Wednesday	12am-12am (Thu)	+30mV
Friday	12am-12pm	+30mV

Table 4:Amperage increases related to the planned outages

Day	Time	Line Current
Monday	12am-12am	165kA (+3.5kA)
Tuesday	12am-12am	161.5kA
Wednesday	12am-12am	165kA (+3.5kA)
Thursday	12am-12am	161.6kA
Friday	12am-12am	165kA (+3.5kA)

The CellSim model dating from the 26th of May 2016 including the 9 Box logic was modified in order to simulate a power cut. CellSim accounts for the evolution of bath temperature and composition, average ledge thickness, current efficiency, mass balance and their impact on the heat losses.

Figure 8 shows a calculation at 165kA before, between and after two 1.5 hours power cuts at 5h and at 11h30. Bath temperature reaches 969°C before the 1st power cut and drops to 939 °C after the 1st power cut. 5 hours after the end of the 1st power cut, the cell is close to its initial state (958°C) and the 2nd power cut is started. The bath temperature after the 2nd power cut is 929°C and it takes approx. 10 hours for the cell to recover its initial state. The slope of bath temperature is steeper after the power cuts since the ledge is thicker (less heat losses).

We expect the minimum bath temperatures predicted by CellSim after the power cuts to be too low compared to reality, since effects on the heat losses during the power cuts, like lower gas emissions and zero metal and bath velocity, are not accounted for.

Increasing the power before the 1st power cut prevents a too low minimum bath temperature and shortens the recovery time between the two power cuts. The disadvantage is that the heating before the 1st power cut is not as efficient as after the power cuts (since heat losses increase before the 1st power cut).

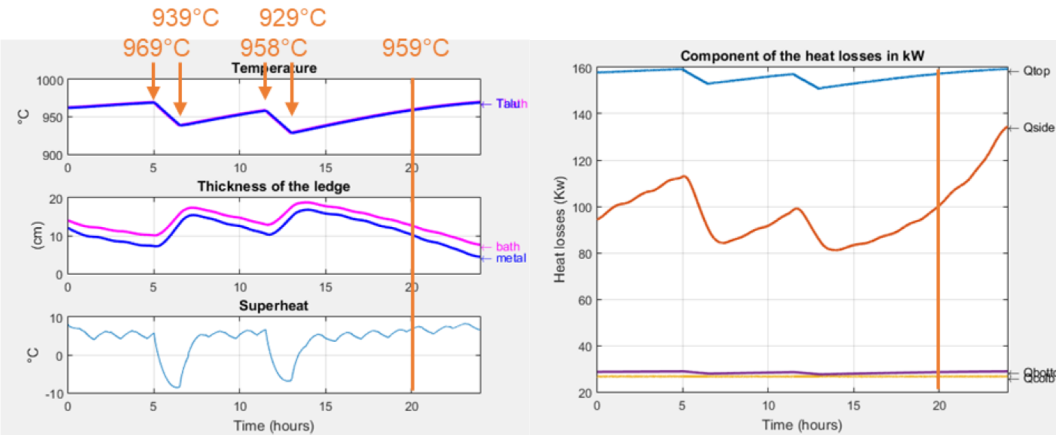


Figure 8: Cells parameters at 165 kA before, between and after the two 1.5 hours power cuts

<u>Ramping up line-current</u>

The problem reducing the number of anode effects due to power outages was solved by ramping up the line current in a particular manner, since after a power outage the standard practice was to ramp-up the power as fast as possible. It was found [11 Mulder LM11] that a more gradual ramp-up led to less anode effects. This phenomenon could be due to very irregular high current density in the pot upon restoration of power, leading to local anode effects even tough there would normally be enough alumina in the cell.

Gains achieved

Energy consumption

Due to the installation of additional busbars, a direct resistance drop of the external losses of about 0.37 μΩ was measured. Furthermore, due to the now very even current distribution through the collector bars (see Figure 9) a similar reduction was achievable.

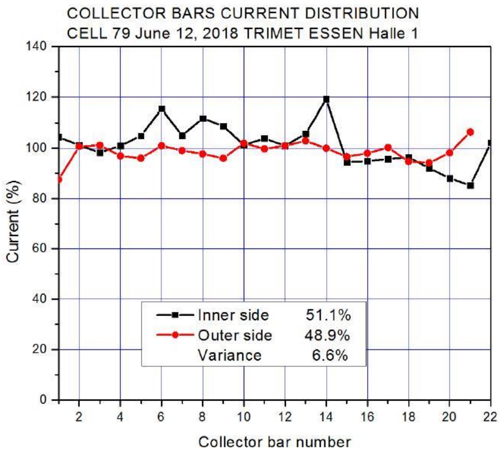
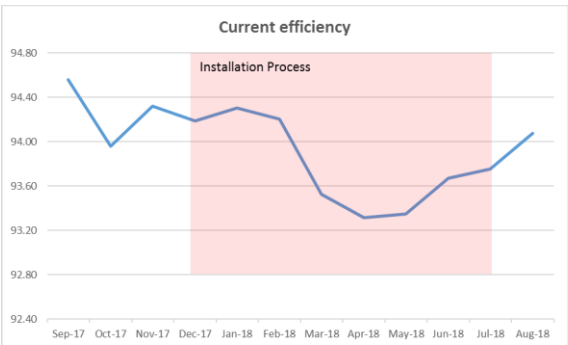


Figure 9: Current distribution with magnetic compensation

Performance during implementing magnetic field compansation

Combining additionnal voltage with increased line current during the retrofitting prevented the potline from cooling too much and causing problems. As it can be seen in Figure10, the overall current efficiency decreased and energy consumption increased.



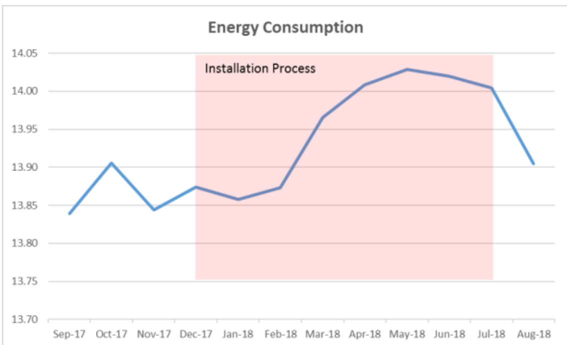


Figure 10: Development of the current efficiency and energy consuption from March 2016 to May 2018

Figure11Figure 9Figure *11* shows the evolution of the anode effect frequency. The current efficiency remained unaffected thanks to measures taken at ramping up the line current. These measures were ramping up to 70 % of the targeted amperage of 162 kA, remain there for 15 minutes before going up to the desired amperage.

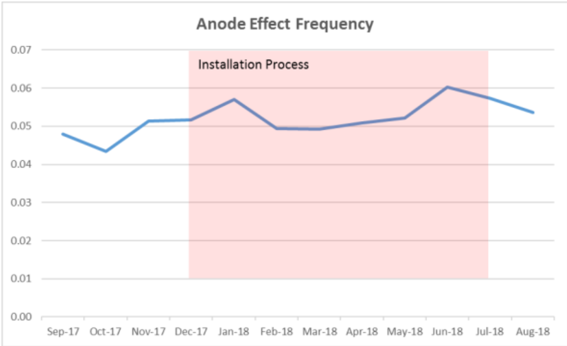


Figure 11: Evolution of the anode effect frequency from March 2016 to May 2018

Summary

This paper described two major changes to a whole potline carried out simultaneously in order to facilitate flexible energy input. Retrofitting a potline comes with challenges for production, process and safety. Managing these aspects has been exercised in Essen successfully. To maintain the stability of the process, timetables for maintenance and operations were developed, which allowed to run the potline in average only 23 hours per day for 6 months. In this period current efficiency and specific energy consumption were worsened. To keep the production and safety to an optimum, a close cooperation between contractors and production was essential and maintained.

Acknowledgement

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