Development, Testing and Deployment of the METRICS Pot Control System

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Abstract

TRIMET Aluminium SE operates six different smelter technologies, all of which are facing the obsolescence of their respective process control systems. After analysing the solutions available on the market, TRIMET decided to develop its own system, METRICS®, in order to retain its core business know-how and to be able to adapt quickly to new challenges in an ever-changing industry landscape.

This paper gives a brief history of the project scope and shows how some of the features of METRICS® helped to speed up the development and encourage innovation: off-the-shelf hardware, model-based design, automated testing, continuous integration, and deployment.

It also gives an overview of the rollout in our German plants: the Essen aluminium smelter was the cradle of the first trials and its first potline with 120 pots is being commissioned. The Voerde aluminium smelter completed the hardware rollout last year, while two thirds of its production were down due to the energy crisis, and restarted its pots in early 2024 using METRICS®.

Keywords: Process control system, Model-based design, Continuous integration, Continuous deployment, Power modulation.

1. Project History and Challenges

TRIMET Aluminium SE operates a patchwork of six different pot technologies within its four smelters in Essen, Hamburg, Voerde in Germany, and Saint-Jean-de-Maurienne in France, see Table 1.

Three different Process Control Systems (PCS) were in use: Kaiser Aluminium's CELTROL for the 188 pots in Voerde, as well as an updated and not compatible version CELTROL CX for the 270 pots in Hamburg, Alesa's BLUEBOX for the 360 pots in Essen, and Rio Tinto Aluminium Pechiney's ALPSYS for the 180 pots in Saint-Jean-de-Maurienne. Figure 1 shows the associated pot controllers.

Table 1. Technologies operated by TRIMET and associated PCS.

Site	Pot Technology		PCS	# Pots
Essen (TAE)	Alusuisse EPT14	PB End-to-End	BLUEBOX	240
	Alusuisse EPT17	PB End-to-End		120
Voerde (TAV)	Kaiser P69	PB Side-by-Side	CELTROL	188
Hamburg (THH)	Reynolds	PB Side-by-Side	CELTROL CX	270
Saint-Jean (TAF)	Pechiney AP18	PB Side-by-Side	ALPSYS	60
	Pechiney AP30	PB Side-by-Side		120
			Total	998

CELTROL BLUEBOX ALPSYS

Figure 1. Pot controllers used in TRIMET smelters.

ALPSYS, which was installed in St-Jean-de-Maurienne in 2003, was the latest PCS within TRIMET. With a service life of 20 to more than 30 years, all TRIMET PCS were facing hardware and software obsolescence and needed to be replaced. CELTROL was discontinued in the early 1990s, while BLUEBOX was discontinued in the 2010s and some functions were integrated in ALPSYS.

It was time for TRIMET to standardize its PCS across the four smelters, to meet existing and future process control challenges: flexible control mechanisms to adapt to fluctuating power supply, virtual battery [4] and potentially CO_2-free aluminium production.

While the solutions available on the market offered proven results and reassuring support, they did not fully meet expectations in terms of costs and ability to implement our own process control ideas, as proprietary hardware and/or software hindered our ability to innovate.

This led TRIMET to make the challenging decision to develop its own PCS, METRICS®, with some key expectations derived from our experience in using previous PCS.

The first was to use a standard Programmable Logic Controller (PLC) to facilitate maintenance and reduce costs. This choice has already been made by others [3] and aims to avoid as much as possible the difficulties encountered with proprietary, outdated hardware and software.

The second was to be able to adapt to the huge diversity of the existing pot technologies. The goal was to develop a generic PCS that could be configured for all the different types of equipment found in the four smelters. From centre bar breaker to the desired number of point feeders, pneumatic or electric beam motors, beam position sensors, bath sensors, shell heat exchangers and other custom developments.

Thirdly, to develop an intuitive Human-Machine Interface (HMI) to facilitate the operator's interaction with the system, allow field observations and feedback, and facilitate training.
Finally, the development framework should be efficient and allow for extensive automated testing to speed up innovation.

2. Model-Based Design

The automotive industry was the first to promote the development of model-based systems on a large scale [1], and this approach began to gain significant ground in the late 1990s and early 2000s.

Model-Based Design (MBD) involves using computer-based models to design and simulate complex systems. Companies like MathWorks, with tools such as MATLAB and Simulink, have been instrumental in advancing MBD in the automotive sector by providing powerful simulation and modelling platforms tailored for engineering applications. These tools enabled engineers to create dynamic system models, perform simulations, automatically test models [2] and generate code for embedded systems, reducing development time and costs.

The reasons that led the automotive industry to MBD seemed to fit our needs perfectly. While cell process control might seem an established knowledge for process control experts, the difficult part of starting from scratch is specifying the control logic in detail for programmers. MBD allows the process control expert to design the control logic directly using a graphical model, with many advantages.

At a conceptual level, the logic can easily be shared, discussed and improved with other process control experts.

At a practical level, the logic is based on state-of-the-art functional blocks that have long been validated by specialists in their respective fields, allowing the focus to be on the why rather than the how. For example, a digital filter is simply defined by its design criteria in terms of amplitude response and bandwidth. Specifying, implementing, and testing such a filter could take weeks for a programmer with no background in Digital Signal Processing. Section 5 gives an example of out-of-the-box Digital Signal Processing.

In addition, the control logic can be tested directly against a simplified pot model, see Figure 2. This is extremely useful for understanding and avoiding unexpected behaviour, especially for systems with very long time constants such as a pot. Most of the control logic situations that would take hours on a real pot can be simulated and verified on a pot model in seconds, allowing known situations to be tested automatically, dramatically reducing commissioning and field testing time for each new control logic release.

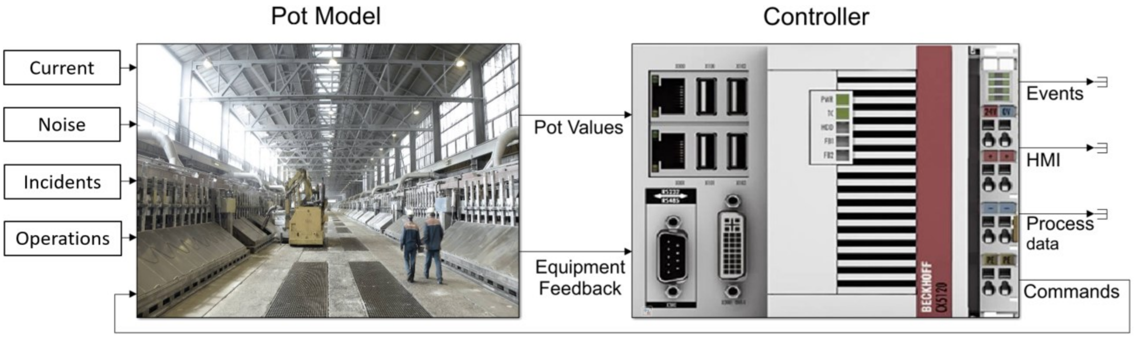

Figure 2. Control logic model tested against simplified pot model.

Finally, the control logic designed by process control experts and automatically tested against a wide range of simulated situations on a pot model is transferred to the PLC via automatic code generation, eliminating human programming errors.

3. Development and Test

A proof of concept quickly confirmed that Model-Based Design fully met our expectations for pot control logic development, with easy prototyping, efficient testing, and reliable automatic code generation.

The initial tests were carried out in Essen using a switch box that provided pot signals to both the legacy BLUEBOX controller and the new METRICS® controller, allowing selection of which control system was in control of each function/equipment. This allowed key functions such as alumina feeding or beam control to be tested progressively, with a fall-back option always available. This switch box proved particularly useful when running tests on other not yet tested technologies such as Kaiser P69 in Voerde or AP30 in Saint-Jean-de-Maurienne. It was possible to carry out daily testing and operator training, while switching back to legacy controller at night or weekends, prior to 24 hours/7 days per week (24/7) testing.

After successful initial tests, a test group of 16 pots was set up to verify operational robustness, while further developing the Level 1 Human Machine Interface (HMI), Level 2 Potline Supervisory, communication services, and databases.

Figure 3. METRICS® L1 HMI in operation in Essen smelter.

This test group was then expanded to 56 pots, see Figure 4, in order to compare performance with the legacy system. This ensured that the tuning of the new system was properly optimized, with key performance indicators such as specific energy consumption or anode effect rate not significantly different from the reference group.

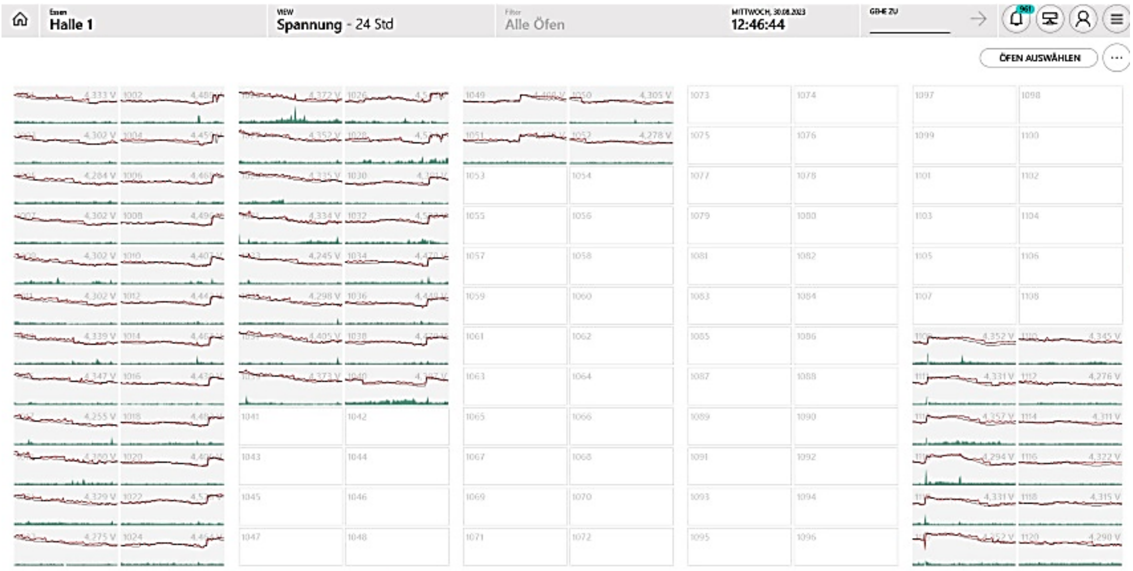

Figure 4. 56 pots test group on Level 2 Supervisory in Essen smelter.

In parallel, a test group of 10 pots was started in Voerde, while Hamburg and Saint-Jean-de-Maurienne are currently preparing the next steps with METRICS® already installed on one test pot in each smelter.

4. Rollout in the Plants

The Voerde smelter was the most worrying in terms of hardware obsolescence, as it was equipped with the oldest version of CELTROL. It was decided to prioritize Voerde and upgrade the entire potline with the new PCS while two-thirds of the pots were down due to the energy crisis. The legacy system was shut down at the end of August 2023 with no fall-back option, and the remaining pots were successfully restarted with METRICS® in the first half of 2024. The commissioning in Essen potline 1 took place in parallel.

Moving from test groups to a system in production managing two potlines and 200-300 pots created conflicting objectives. The key expectations for a PCS in production are robustness and stability, but, in a situation where not all supervisory developments have been completed, the regular feedback from our process specialists in all four plants led to a constant flow of improvements.

Continuous Integration/Continuous Deployment (CI/CD) has played here a crucial role in facilitating the rollout of software, by automating and streamlining the entire process from development to production. Each new software release triggers an automated build process which ensures that changes are automatically compiled, tested, and packaged, reducing the risk of human error and ensuring consistency. Automated testing starts with unit testing on each module and goes through to full integration testing, using a hardware-in-the-loop (HIL) integration platform. This platform allows plant-specific environment and Input/Outputs (IOs) to be mimicked to ensure that all expectations are met, eliminating the need for tedious human testing of repetitive checks. Figure 5 shows the pot controller connected to a pot simulator via plant-specific IOs.

Figure 5. Hardware in the Loop (HIL) with pot simulation.

This level of automation has allowed us to meet our expectations for system stability, while maintaining the pace of new software releases.

5. Continuous Process Control Improvement

TRIMET has a long history of innovation in the field of power modulation [4, 5]. As highlighted in [5], the addition of renewable energy to the grid has shortened the time interval at which modulation occurs, leading to the need to adapt the way process control reacts to these fluctuations. This is both a challenge, and an opportunity.

In the Essen smelter, short-term power modulation can be characterised by amperage steps several times a day, as shown in Figure 6.

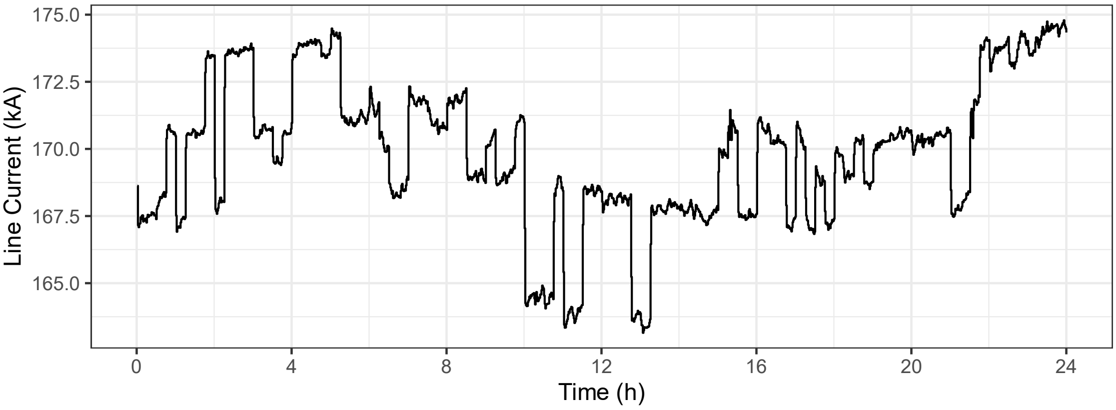

Figure 6. Example of daily line current fluctuations.

Pseudo-resistance is commonly used by process control systems to filter out noise caused by variations in line current [6]:

$$R = \frac{V - V_{ext}}{I} \tag{1}$$

where:

R Pseudo-resistance, Ω
V Cell voltage, V
V_{ext} Extrapolated voltage, V
I Amperage, A

The extrapolated voltage (V_{ext}) corresponds to the zero current intercept of the voltage versus current regression around the operating point and is typically expected to be in the range of 1.6–1.7 V depending on cell condition and current density [6].

The enhanced prototyping and data analysis capabilities of METRICS® combined with these frequent current variations provided the opportunity to track the evolution of the extrapolated voltage for each individual cell 20–50 times a day over several weeks using a simple Simulink regression subsystem, see Figure 7.

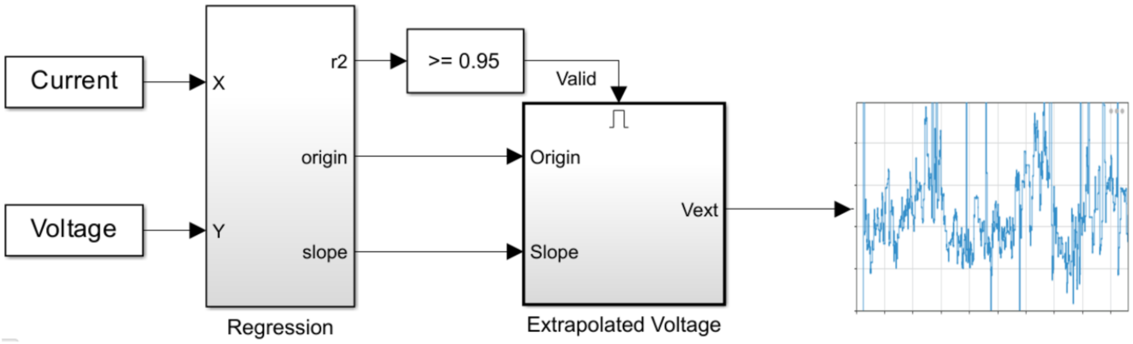

Figure 7. Voltage versus current regression subsystem.

According to Haupin [7], the extrapolated voltage depends on many factors with alumina concentration in the bath, cell temperature, and anode and cathode current density playing a key role. Other factors such as position in the potline, work practices for anode change or tapping, also have an influence on the current densities, and therefore an indirect influence on the extrapolated voltage. Low alumina concentration can lead to low or even negative extrapolated voltage, whereas low temperature and higher anode and cathode current densities tend to increase the extrapolated voltage.

Cell temperature is the only factor that is directly measured, allowing the correlation with extrapolated voltage to be examined. The box plot shown in Figure 8 is produced by relating the smoothed extrapolated voltage calculation to the temperature around the time of measurement on thousands of observations per day.

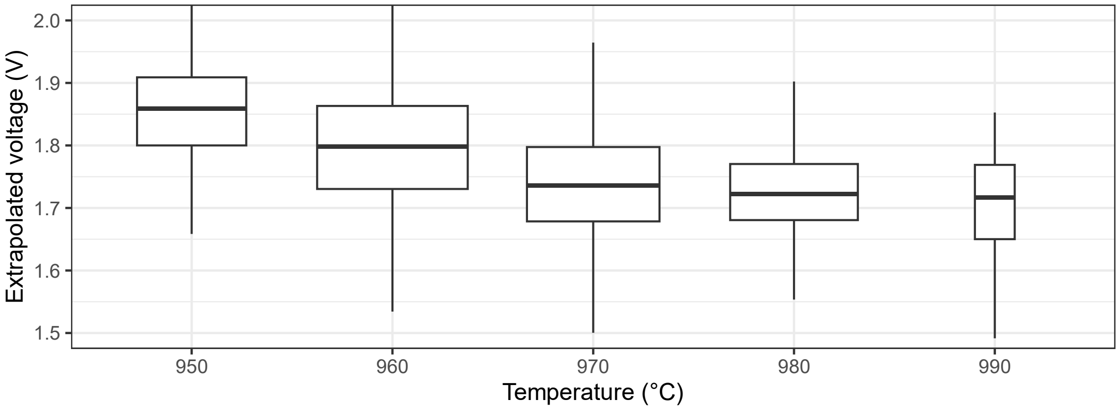

Figure 8. Extrapolated voltage versus temperature.

This boxplot clearly shows the very significant dependence of the extrapolated voltage on temperature and helped to establish a new reference for the extrapolated voltage used in the pseudo resistance calculation for each plant, closer to 1.8 V than the often used 1.65 V.

The smoothed calculation of extrapolated voltage is even more interesting on a cell-by-cell basis, as trends in extrapolated voltage anti-correlate with temperature and tend to lead temperature trends, providing an early indicator of cell condition, see Figure 9.

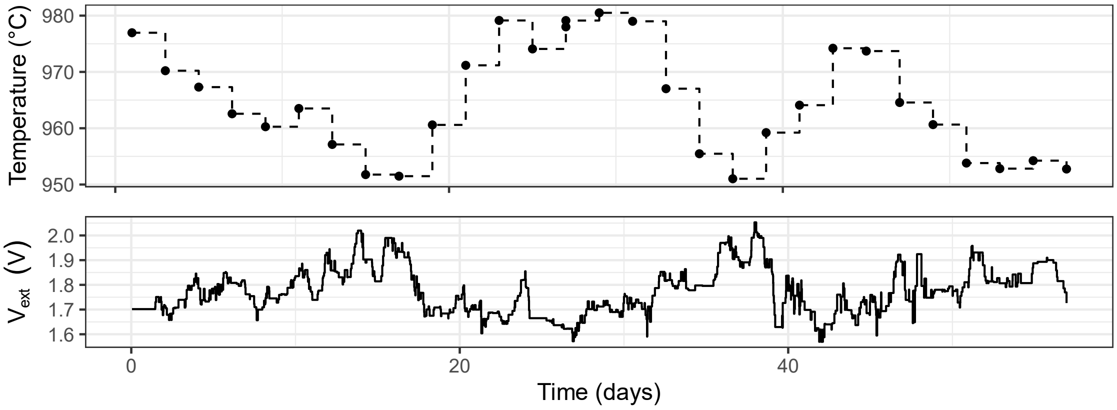

Figure 9. Extrapolated voltage vs temperature on a single cell.

The dependence of the extrapolated voltage on the alumina concentration was also investigated, taking into account the fact that the alumina concentration is not measured, but is expected to be lower than the average before an anode effect. Due to the limited number of extrapolated voltage calculations before each anode effect, no smoothing was possible, resulting in more scattered data. However, a significant trend was also measurable, see Figure 10, showing the influence of alumina concentration on the extrapolated voltage. This opens again new possibilities for detecting abnormal pot situations and preventing events such as anode effects.

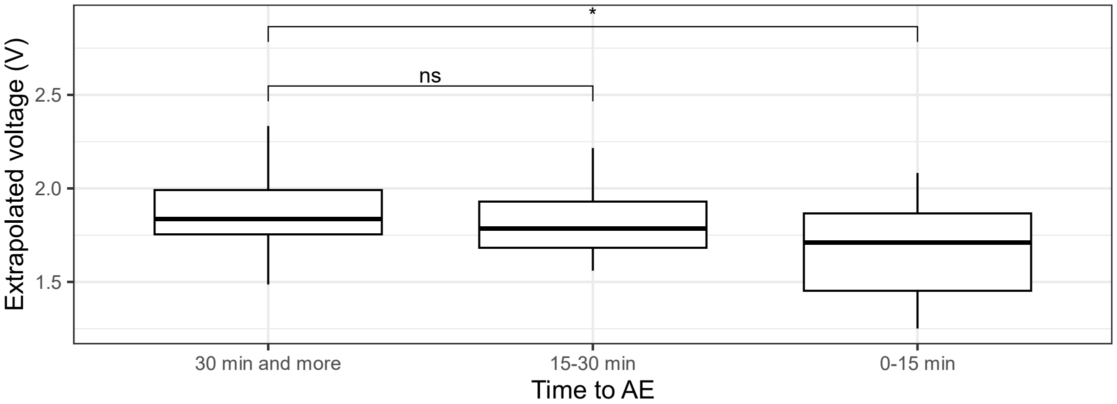

Figure 10. Extrapolated voltage vs time to next anode effect.

As the prototype regression subsystem confirmed its potential, it qualified for production release within weeks.

6. Conclusion

METRICS® has demonstrated its ability to adapt to different pot technologies and, as a first objective, to replace all TRIMET obsolete legacy Pot Control Systems, with comparable results. More than 200 pots are already controlled by the new system in Essen and Voerde, while tests are underway in Hamburg and Saint-Jean-de-Maurienne. It perfectly meets the initial specifications with efficient prototyping, fast release cycle, ease of use, and enhanced data analysis capabilities.

TRIMET is committed to further developing its PCS to drive innovation and meet the challenges of power modulation and low carbon operation.

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