Improved Control of an Electric Arc Furnace in a PGM Smelting Operation

ETA Operations, Valterra Platinum and North-West University

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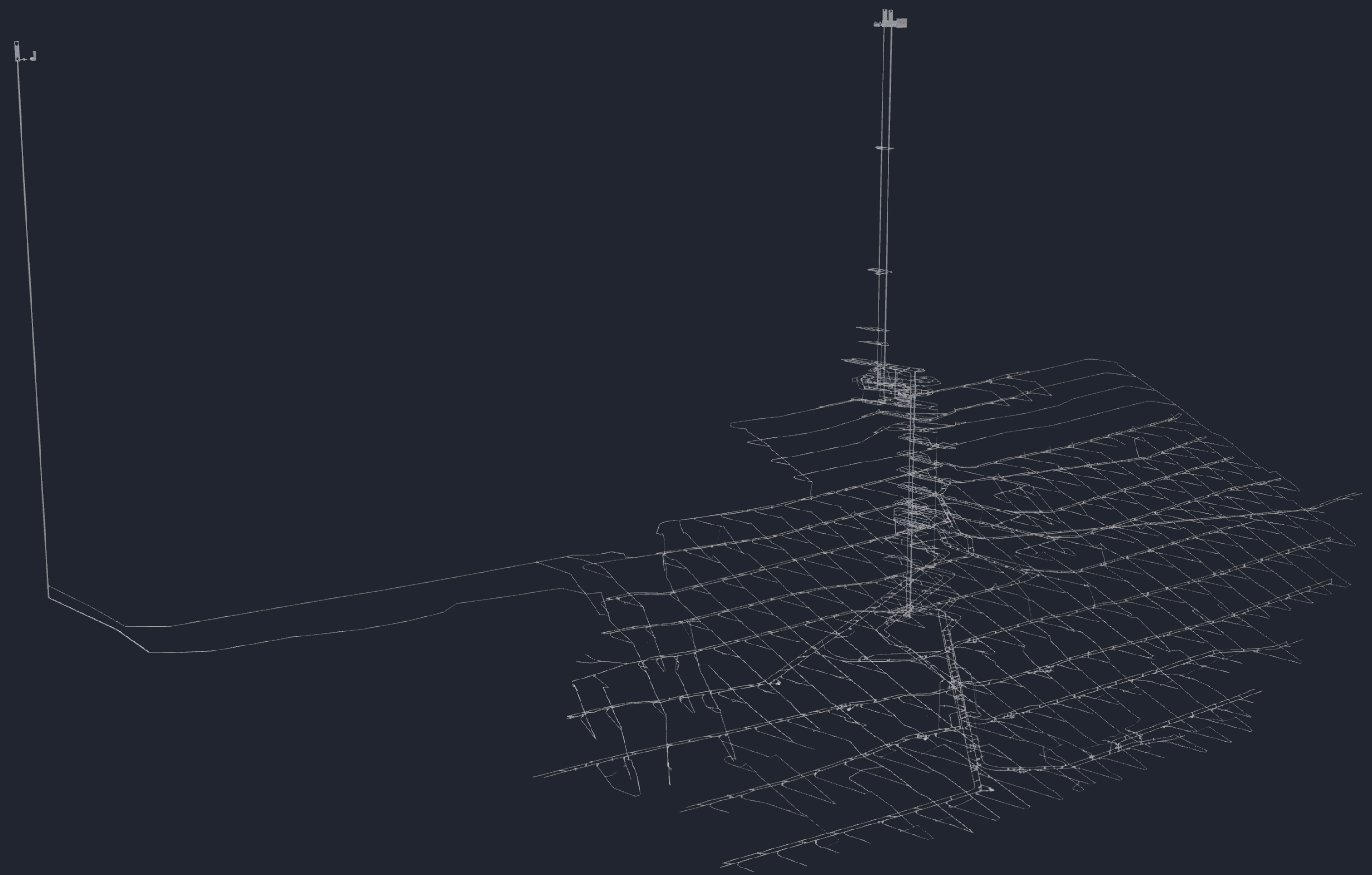

Outline

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Introduction

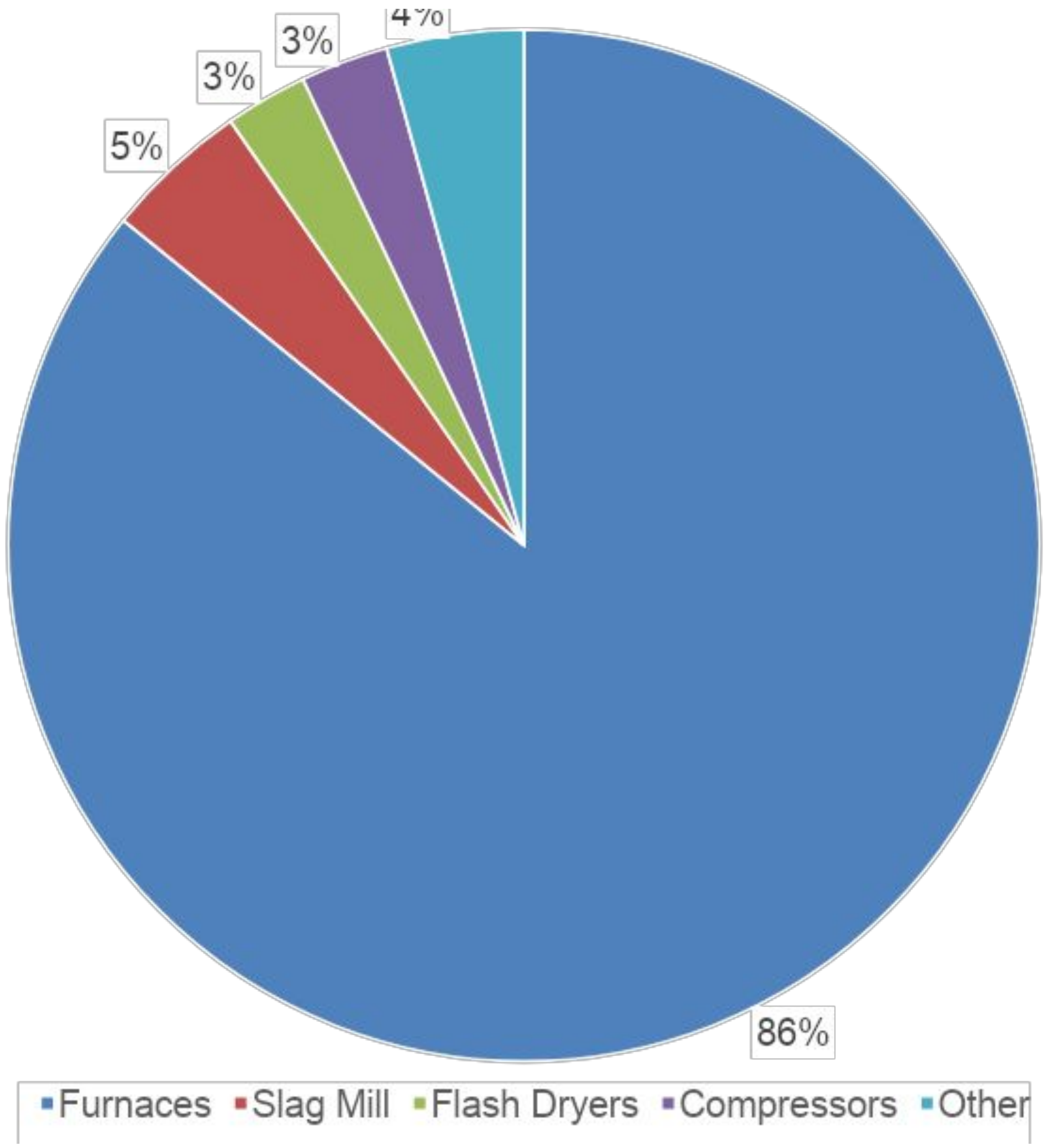
- PGM production has historically been vital to South Africa’s economy
- Production has declined over the past century → increased production costs *(Minerals Council South Africa, 2021)*
- Rising electricity prices over the past decade have made operations less sustainable *(Power Optimal, 2021)*

Focus Areas:

- Enhance operational efficiency and energy productivity
- Implement **Energy Efficiency Initiatives** and **Energy Conservation Measures (ECMs)**
- Assess electrical energy consumption across Waterval Smelter sections

Observation:

- **Electric Arc Furnaces (EAFs)** are the primary drivers of total electrical energy consumption



Introduction

Overview

- Waterval Smelter operates **two** Six-in-Line Electric Arc Furnaces (EAFs) each rated at **34 MW**

Furnace Stability and Control

- **Furnace stability** is a major factor influencing energy productivity
- One aspect of stability depends on **electrical control performance**
    - Includes **resistance (immersion) control** and **power control** *(Snodgrass et al., 2024)*

Objective of study

- Investigate the current **resistance control** to improve energy efficiency and furnace productivity

Literature Insights

Previous Research

- *Hernandez & Onofri (2022): Optimal control model – optimal voltage & impedance SPs to reduce radiation losses*
- *Nikolaev et al. (2014): Mathematical model – analyses furnace electrical characteristics and electrode immersion dynamics. This resulted in finding required specific conductivity settings*

Research Gap and Need

- Limited research focused on **electrode immersion control improvement** in EAFs
- Identified need to **evaluate and improve performance** of the existing electrode immersion control system

Methodology

Control Modes

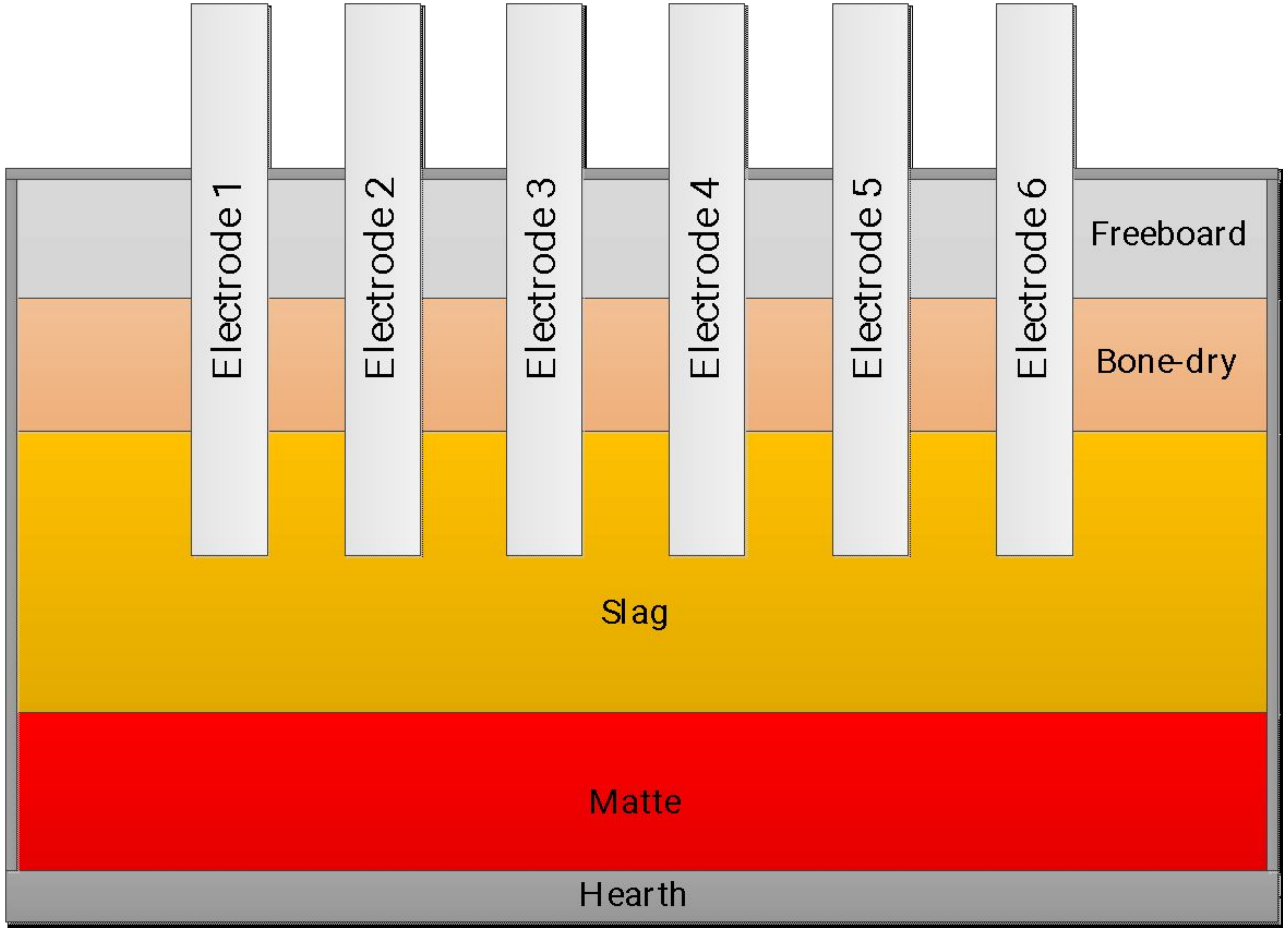
- Furnaces use **resistance (immersion)** and **power control**
- **Power control** is secondary, using **on-load tap changers**

Immersion (Resistance) Control

- **Pulse control** applied to solenoid valves
- **Hydraulic valve speed** adjustable at valve stand
- Each **PLC resistance controller** sends pulses with variable duration/gain
    - Raises or lowers electrode to maintain resistance setpoint

Control Logic

- **Deadband:** ±0.2 mΩ
- Controller acts only when resistance moves **outside** the deadband
- Once resistance returns **within range**, control action pauses



Methodology

Resistance Control Performance Evaluation

•Study focused on **resistance control** of two Six-in-Line furnaces at **Waterval Smelter**

•**Power control** excluded — resistance control has priority in the control philosophy

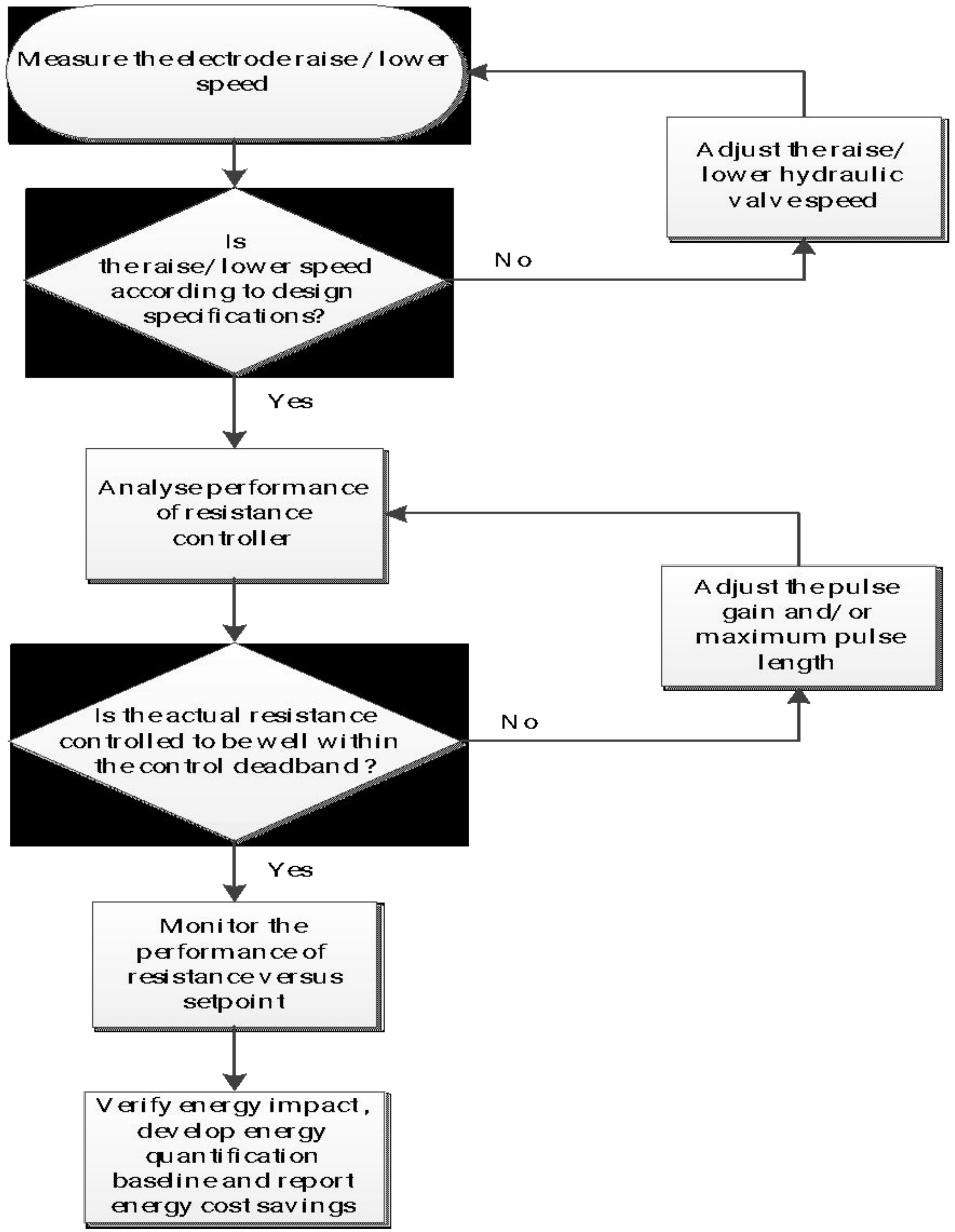
Improvement Process

1. **Measure and adjust** actual raising and lowering speeds of each electrode
2. **Evaluate** individual electrode resistance controller performance
3. **Fine-tune** key parameters:
    1. Pulse gain
    2. Maximum pulse length

Sustainability and Impact

•**Weekly performance monitoring** required to maintain control stability

•**Energy impact** must be **quantified and verified**



Methodology

Energy Impact Calculation

- **Baseline Development**
  - A baseline *Specific Energy Consumption (SEC)* is developed prior to implementing the initiative.
- **Performance Tracking**
  - Baseline SEC is multiplied by the *concentrate feed* during the performance period.
  - This gives the **predicted energy consumption (EP)**.

$$EP = EIB \times PPA$$

Actual Energy Impact

- Actual energy consumption (**EA**) is compared to predicted consumption (**EP**).
- The difference quantifies the energy impact of the resistance control optimization.

$$EI = EP - EA$$

Results and discussion

Electrode Hydraulic Speed Adjustments

- **Objective:**

Improve resistance control by verifying and correcting electrode hydraulic speeds.

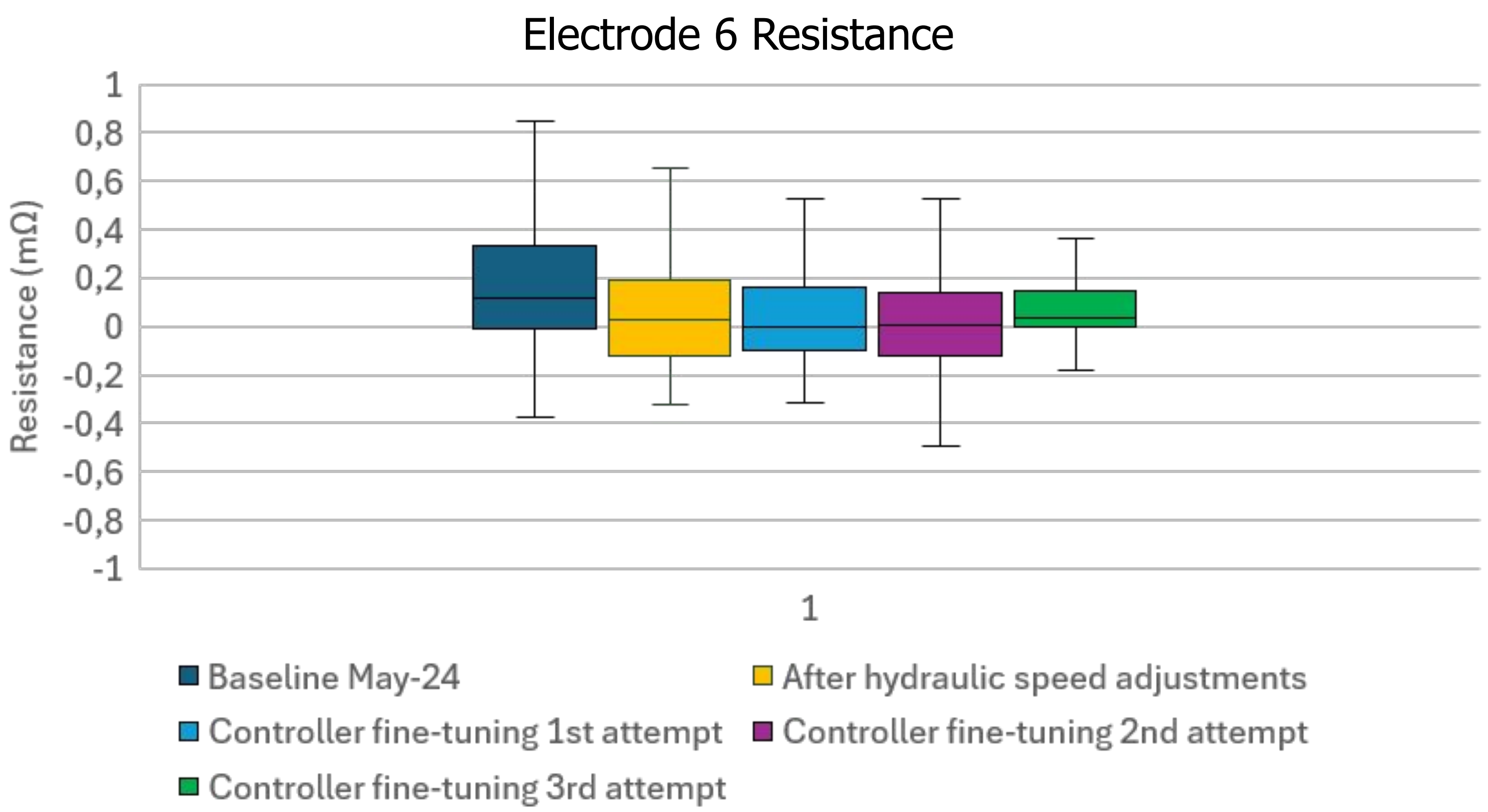
- **Step 1: Measurement**
  - Measure both *raising* and *lowering* hydraulic speeds on site.
  - Actual electrode speeds were physically recorded during testing.
- **Step 2: Adjustment**
  - Adjust hydraulic settings to achieve correct operating speeds.
- **Target Speed Ranges:**
  - **Raising speed:** 100 mm in **12–18 seconds**
  - **Lowering speed:** 100 mm in **18–25 seconds**

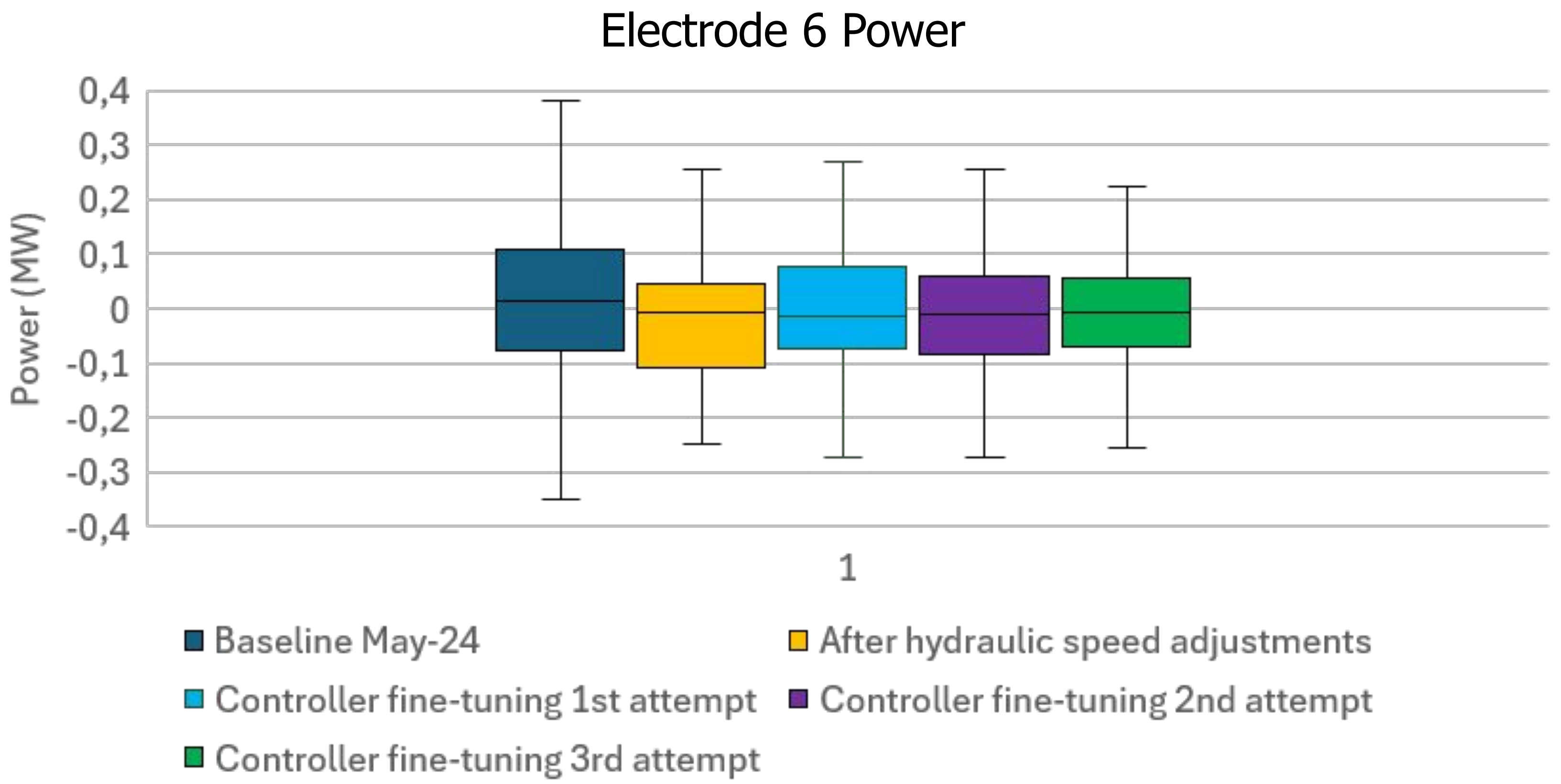
No	Baseline measurement		1st Adjustment		2nd Adjustment		Comment
Electrode 1	Raise time (s)	17.14	Raise time (s)	18.1	Raise time (s)	18	Didn't adjust raise speed
	Lower time (s)	9.14	Lower time (s)	13.6	Lower time (s)	21.6	Decreased the lower speed
Electrode 2	Raise time (s)	18.08	Raise time (s)	N/A	Raise time (s)	N/A	Didn't adjust raise speed
	Lower time (s)	21.85	Lower time (s)	N/A	Lower time (s)	N/A	Didn't adjust lower speed
Electrode 3	Raise time (s)	32.12	Raise time (s)	30.5	Raise time (s)	31.5	Couldn't increase raise speed. It's at maximum
	Lower time (s)	22.17	Lower time (s)	26.1	Lower time (s)	32	Decreased lower speed
Electrode 4	Raise time (s)	18.09	Raise time (s)	N/A	Raise time (s)	N/A	Didn't adjust raise speed
	Lower time (s)	21.02	Lower time (s)	N/A	Lower time (s)	N/A	Didn't adjust lower speed
Electrode 5	Raise time (s)	33.09	Raise time (s)	34	Raise time (s)	N/A	Couldn't increase raise speed. It's at maximum
	Lower time (s)	18.56	Lower time (s)	36	Lower time (s)	N/A	Decreased lower speed
Electrode 6	Raise time (s)	19.71	Raise time (s)	18.2	Raise time (s)	N/A	Didn't adjust raise speed
	Lower time (s)	16.02	Lower time (s)	24.1	Lower time (s)	N/A	Decreased lower speed

Results and discussion

Improved Resistance Control Performance Impact

- **Illustrative Example:**
  - Box and whisker analysis shown for **Electrode 6** (same method applied to all electrodes).
- **Box Plot Interpretation:**
  - **Middle line:** Average resistance value (target = **0 mΩ**) → indicates setpoint consistency.
  - **Top and bottom ends:** Represents the operating band.
- **Performance Improvements:**
  - Slight improvement in **resistance control** after electrode speed adjustments.
  - Further improvement achieved after **controller fine-tuning**.
  - **Enhanced resistance control** led to better **power control stability**.
  - Overall **power control performance** improved as furnace operation is primarily governed by resistance.





Results and discussion

Resistance Controller Performance After Fine-Tuning

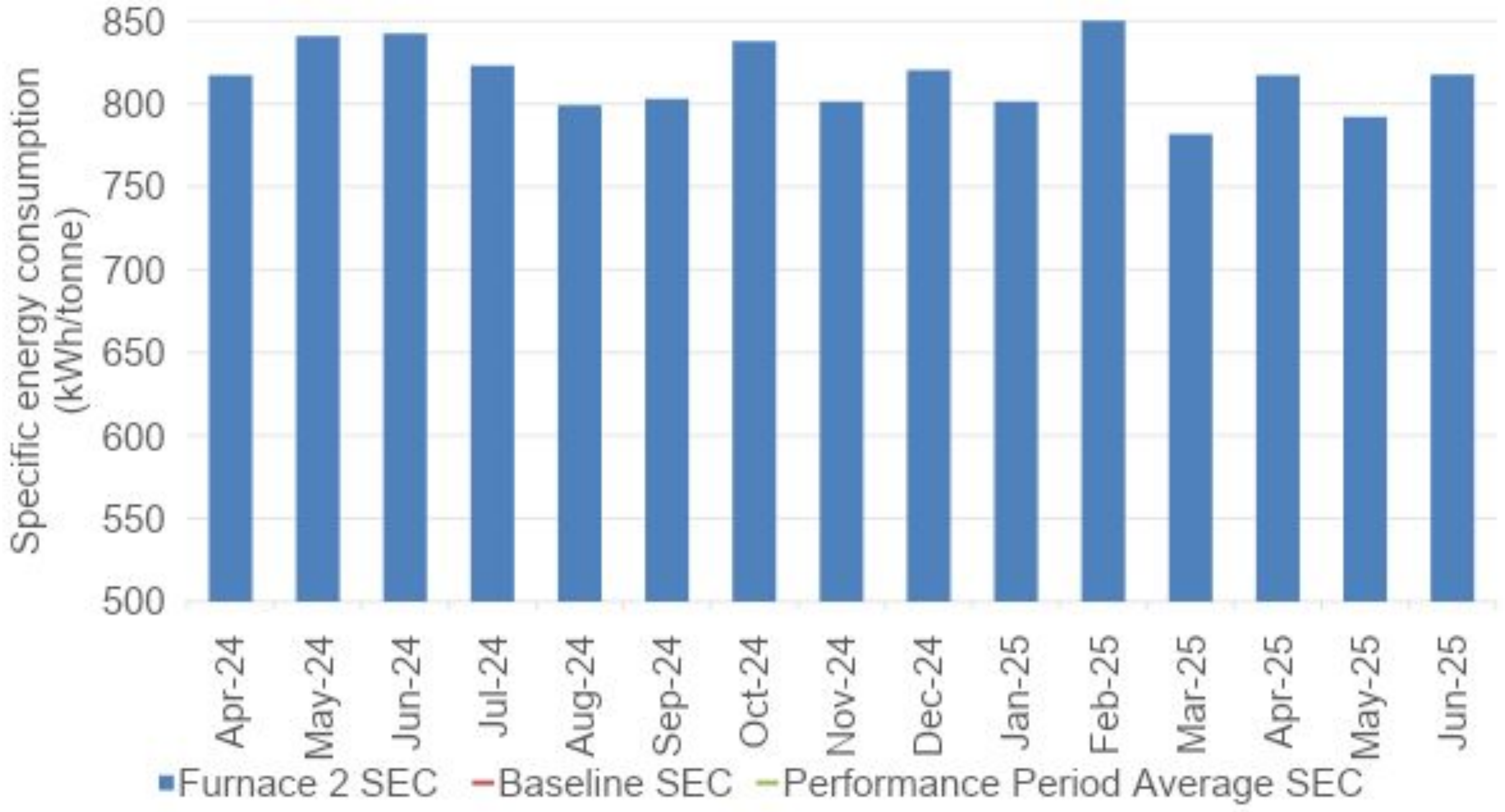
- Improved resistance control band for each electrode.
- Actual resistance closely aligns with setpoint.
- Operating within a narrower band and balanced around zero.

Electrode no	Maximum difference between resistance and setpoint (mΩ)	Minimum difference between resistance and setpoint (mΩ)	Average difference between resistance and setpoint (mΩ)	Upper band of difference between resistance and setpoint (mΩ)	Lower band of difference between resistance and setpoint (mΩ)
1	0.34	-0.26	-0.04	0.08	-0.11
2	0.29	-0.23	-0.04	0.09	- 0.15
3	0.25	-0.34	-0.08	0.03	-0.17
4	0.4	-0.34	-0.11	0.04	-0.21
5	0.48	-0.23	0.03	0.15	-0.09
6	0.36	-0.18	0.03	0.15	-0.003

Results and discussion

Energy Savings Impact Quantification

- Improved **resistance control** on **Furnace 1** and **Furnace 2** resulted in:
  - Enhanced **power stability**
  - Improved **overall furnace stability**
- Improvement reflected by **lower Specific Energy Consumption (SEC)**
- **Furnace 2** used as an example to illustrate SEC improvement relative to the **Baseline SEC**
- **Results:**
  - **Annual energy savings:** 8.25 GWh
  - **SEC improvement:** 3.03 %
  - **Energy cost savings: R 15.17 million/year**
  - Achieved **without any capital expenditure**



Conclusion

- Resistance control strategy was evaluated based on limited available literature.
- Initial analysis of resistance and power control bands showed the need to measure and adjust electrode hydraulic speeds and the fine-tuning of individual resistance controllers.
- Improved resistance control resulted in achieving resistance setpoints more consistently, narrower control bands, and improved power control stability.
- **Results** revealed significant **energy cost savings** achieved by improving **electrical control**
- Further improvements possible through **proportional control valves**, **feed control optimization**, and **power control optimization** for greater furnace stability and efficiency.

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