Reducing Perfluorocarbon Generation at Tomago Aluminium Company through Improved Anode Effect Treatment

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https://doi.org/10.71659/icsoba2025-al051

Abstract

Tomago Aluminium Company (TAC), the largest aluminium smelter in Australia, recognized a need to reduce perfluorocarbon (PFC) emissions to meet their decarbonization targets. The existing anode effect treatment (AET) settings reflected the historical methodology of progressively deeper "loops" to squeeze/un-squeeze the anode-cathode distance (ACD) and pump the displaced bath into and out of the channels and feed zones. The anode effect treatment (AET) efficiency was found to be lower than comparable smelters. After careful data analysis, a 3-stage improvement process was defined: standardization across three potlines, refinement of the existing loop settings, and finally re-configuration of the loops. Parameters were reviewed, risk assessed and trialled progressively through each of the three stages over a four-month period. The trials demonstrated a statistically significant, 50 % reduction in estimated PFC emissions by reducing the anode effect duration (AED) and without impacting anode effect frequency (AEF). The new settings were deployed on all three potlines at end of 2023 and the 50 % PFC reduction has been observed and sustained. This paper describes the collaboration between TAC and the RTA technical teams (in Australia, France and Canada) to develop an experimental process that achieved this significant milestone for TAC.

Keywords: Anode effect frequency (AEF), Anode effect treatment (AET), Anode-cathode distance (ACD), Perfluorocarbon (PFC) emissions, Decarbonization.

1. Introduction: Data Analysis of TAC Estimated PFC Generation in All 3 Potlines

Tomago Aluminium Company (TAC), the largest aluminium smelter in Australia, recognized a need to reduce perfluorocarbon (PFC) emissions to meet their decarbonization targets. The existing anode effect treatment (AET) settings reflected the historical methodology of progressively deeper "loops" to squeeze/un-squeeze the anode-cathode distance (ACD) and pump the displaced bath into and out of the channels and feed zones. The anode effect treatment (AET) efficiency was found to be lower than comparable smelters.

TAC data was analysed to understand the contributors to high estimated PFC generation. Following were the observations:

- 66 % of total PFC generated was from manually treated anode effects.
- 33 % of total PFC generated was from successfully treated (Auto) anode effects.
- 1 % of total PFC generated was from new cells.

Further analysis of AET squelch sequences was carried out to increase the Successful AET rate and reduce the Manual AET rate and hence improve PFC generation. Physical reasons of AEF and multiple AE were out of scope for this work. Observations of data analysis guided the work to be in two categories as explained in following sub-sections.

1.1 Successfully Treated (Auto) Anode Effects

Data analysis was done to understand the efficiency of AET for successfully treated anode effects. Following were the observations:

- Table 1 clearly shows that L2 had higher (62 %) successful AET in Loop 0 & 1 compared to L1 and L3 (50 %)
- Rate of successful AET on loops 0 and 1 are in general lower when compared with similar smelters.

Table 1. Percentage of successful AET in different loops for all three lines.

	All Values in %		
AET Loop Sequence	Line 1	Line 2	Line 3
0	27	33	22
1	23	29	26
2	20	18	23
3	15	11	16
4	9	6	8
5	6	3	5
Total	100	100	100

These observations prompted investigation of what was different in L2 and to maximise successful AET in loops 0 and 1.

1.2 Manual AET (Including Failed Auto Treatment) Anode Effects

The reasons/causes for Manual Anode effects were investigated, with the following observations:

- Auto AET failed and declaration of impossible anode effect was the major contributor.
- Recent AE declaration causing impossible AE was 2nd biggest contributor.

These observations prompted investigation of each step (loop) of the automatic AET to understand reasons for failure. Multiple anode effect causes were largely out of scope for this work, though it was considered that some AEs might be reappearing because they were not treated effectively the first time.

2. Existing AET Configuration

The existing settings for AET in ALPSYS® reflected the historical methodology of progressively deeper “loops” to squeeze/un-squeeze the ACD and pump the displaced bath into and out of the channels and feed zones:

- Progressively deeper loops (preliminary + 5 elementary loops).
- Short duration “hold” with the ACD squeezed.
- Voltage checks for success only when each loop was completed with the ACD un-squeezed.

- Pumping action displaces bath into the channels /feed zones, thought to be good for alumina dissolution and dispersion.
- A simple recovery (adjustment) phase to progressively restore the cell voltage close to target once the AE is provisionally declared out.

Figure 2 below is a calculated simulation of the configuration of the AET loops on all 3 lines at Tomago, using an arbitrary 27 mm ACD reference. The distances are calculated from the ALPSYS® parameters for each sequence and the up and down speeds. Note that the ALPSYS® speed parameters have been validated with measurements in the last 3–4 years.

Figure 1 clearly shows that the preliminary loop (0) was configured differently on L2 to the other two lines, causing each loop to reach an estimated 1 mm deeper. The elementary loops 1 to 5 were configured identically, noting that the first elementary loop has 3 down/up orders, and each subsequent loop adds another down/up order. This gave an indication of a potential reason that L2 had higher AET efficiency for loops 0 and 1.

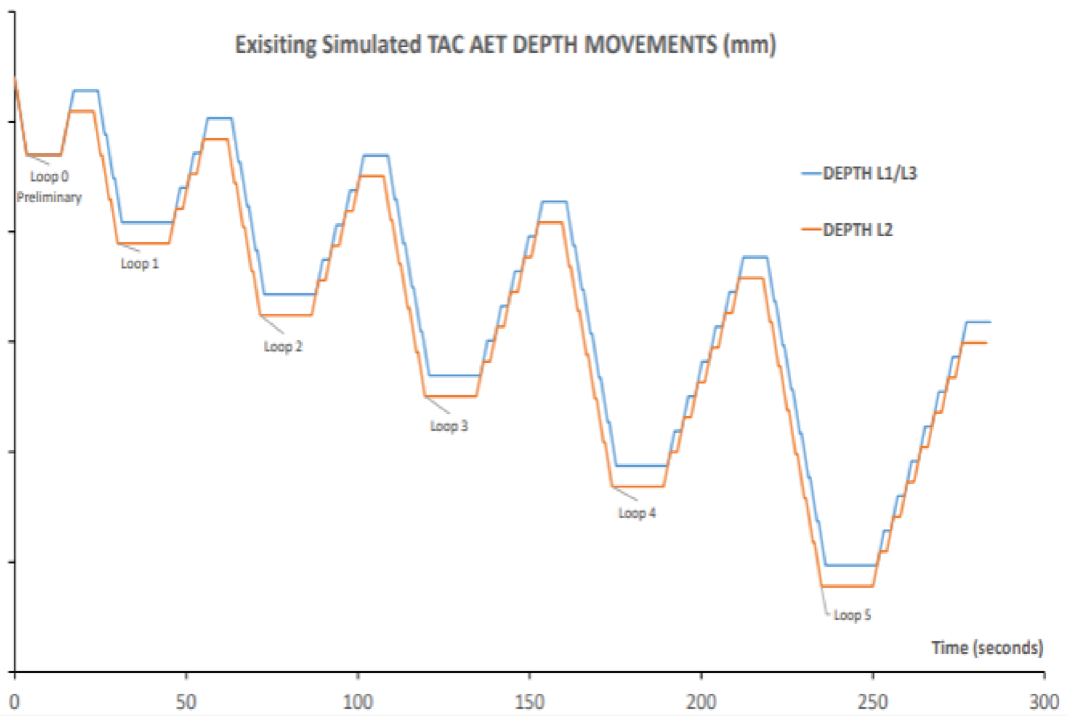


Figure 1. Existing simulated TAC AET depth movements.

3. Risk Assessment

Most of the parameters that configure the AET sequence illustrated in Figure 1 are not able to be accessed by staff at Tomago via the ALPSYS® interfaces. A project team was made with the broader RTA technical teams to develop detailed understanding of the ALPSYS® AET configuration parameters. This facilitated an effective ALPSYS® parameter investigation, risk assessment and tuning at TAC.

There have been incidents in the past at multiple smelters where AET parameter changes have caused either excessive bath spillage (excessive down orders) or risk of open circuit (excessive up orders). In recognising that there are inherent risks with changing AET parameters that interact with each other, a methodology with manageable steps with independent technical and practical risk assessments was essential.

4. Proposed Improvement Methodology

Three specific stages improvement methodology was identified in June 2023:

- Stage 1: (June–July 2023) Standardise all Lines to the Line 2 settings. As outlined earlier, with Line 2 > 60 % (compare Line 1 and 3 – 50 %) of automatic terminations successful in either loop 0 (preliminary) or 1, It was decided that this would be a single parameter change on Line 1 and 3 to match Line 2 and achieve approximately a 1 mm increase in depth.
- Stage 2: (Aug–Sept 2023) Increase the depth of the preliminary loop to the maximum practical with a single order of TAC beam motor control. Benchmarking and discussion with the other RTA sites identified that most target a significant ACD reduction in the initial sequence. Increasing the depth of the preliminary loop was the next logical step for Tomago, though it would be limited by the relatively slow beam motors and short maximum run-time. This stage would still retain the existing elementary loop settings.
- Stage 3: (Oct–Nov 2023) Modify the preliminary and elementary loops to match best practice at other RTA sites [1]. The exact design of Stage 3 would not become clear until the hidden parameters in ALPSYS® were understood and benchmarking other RTA sites (using ALPSYS® or other control systems) while Stage 1 and 2 were executed.

5. Stage 1 and 2 Trial Summary and Findings

Stages 1 and 2 were deliberately narrow in scope to build confidence that our method of risk assessment was effective in managing the risk.

5.1 Stage 1: Standardise on Line 2 Settings

Following risk assessment and a 5-cell proof of concept on Line 1 and Line 3, the modified setting of Stage 1 parameter change was applied remotely by the ALPSYS® team in France to all cells by 13 July 2023. With the modest parameter change, detailed analysis of the impact was not warranted and for the following anode rota, the AET kill rate in Loop 0 or 1 was consistently > 54 %; a modest improvement that fell short of previous Line 2 performance. The decision to proceed to Stage 2 was justified given the expected benefits of this change were too small to measure with significance.

5.2 Stage 2: Increase the Depth of the Preliminary Loop to the Maximum Practical with Tomago Beam Motor Control

As previously outlined, by increasing the effectiveness of the preliminary loop with no change to the subsequent elementary loops, a modest increase in the proportion of AEs terminated in Loop 0 or 1 was anticipated.

The constraint for Stage 2 was the maximum motor energisation time, as the preliminary loop in ALPSYS® has a single down order and a single up order. TAC Line 2 and 3 control panels have a physical timer limiting this to 5 seconds, while Line 1 is limited to 8 seconds. TAC advised that consistent settings across all lines was preferred, so the 5 second limit was applied to all lines.

Stage 2 settings were applied remotely by the ALPSYS® team in France on all lines by mid-September. The implementation of the parameter changes was done in the early evening at TAC, so that ALPSYS® team in France were available to react if undesirable consequences occurred.

Figure 2 compares the calculated simulations of the configuration for AET proposed in Stage 2 with Stage 1.

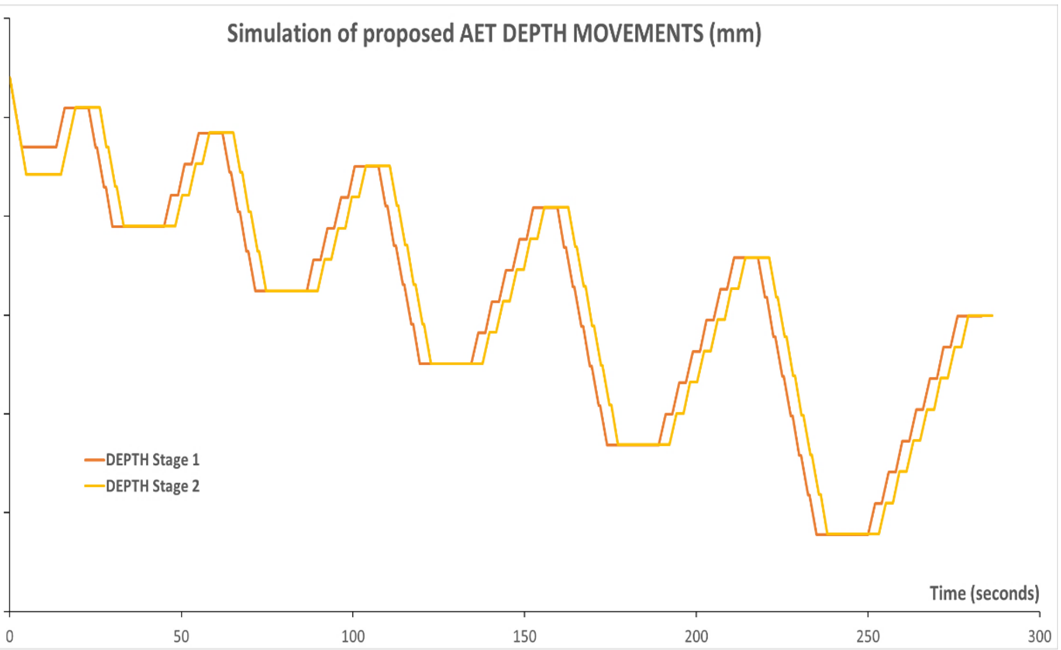
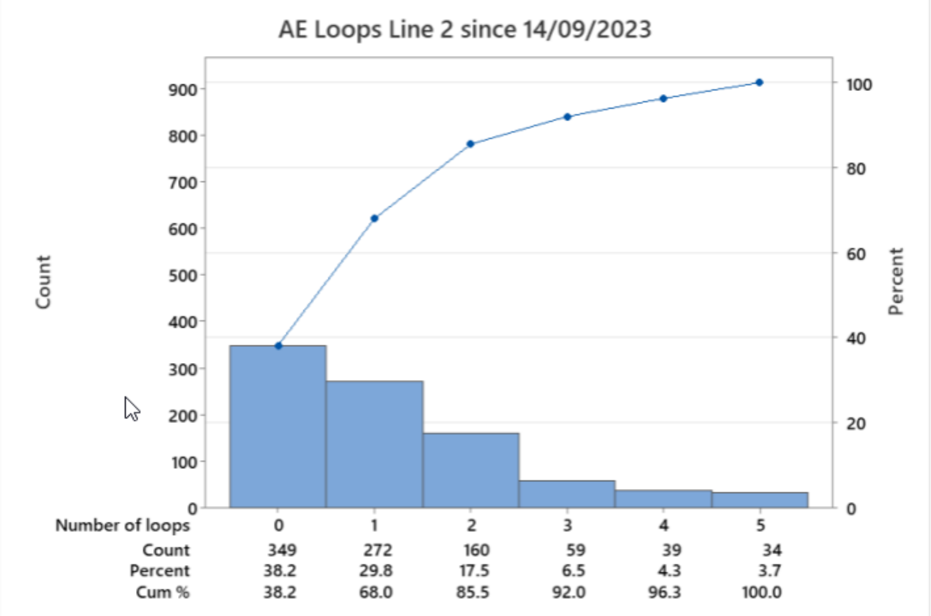


Figure 2. Simulation of proposed AET depth movements.

5.3 Observations and Conclusions from Stage 1 and 2 Trials

Figure 3 demonstrates that on Line 2, the Stage 2 settings were delivering a 68 % AE killing rate in Loop 0 or 1 (Line 1 and 3 were both 64 % or better). This was a modest improvement on the starting point before Stage 1.



Number of loops	0	1	2	3	4	5
Count	349	272	160	59	39	34
Percent	38.2	29.8	17.5	6.5	4.3	3.7
Cum %	38.2	68.0	85.5	92.0	96.3	100.0

Figure 3. Successful AE terminations by loop number with stage 2 (Line 2 example from August–September 2023).

Figure 4 demonstrates that large up orders during AET squelch brings the AE back in some cases.

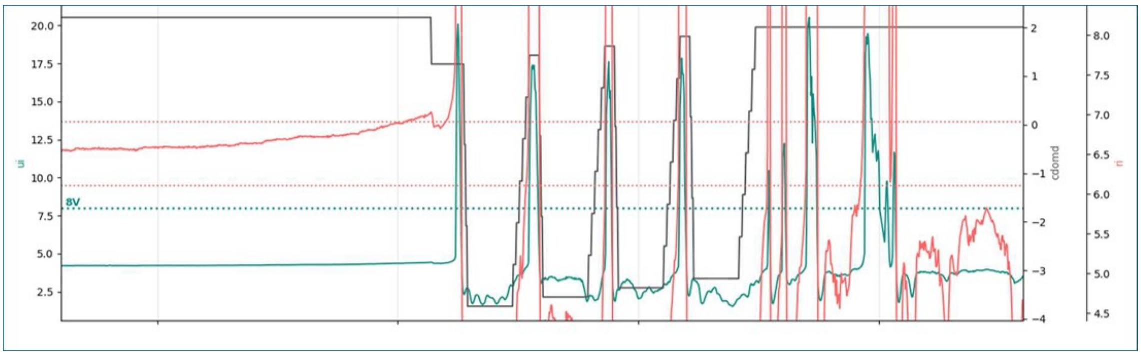


Figure 4: Example of AE voltage returning after big up orders during AET squelch.

6. Stage 3 Trial Summary and Findings

Having demonstrated that the collaboration model had safely delivered modest improvements with simple parameter changes in Stage 1 and 2, the intent of Stage 3 was a more significant reconfiguration of the ALPSYS® parameters to apply best practice learnings.

Using learnings from Stage 1&2 and thorough internal RTA benchmarking, an original Stage 3 proposal was discarded, and a new one was proposed.

6.1 Stage 3 Proposal

The best practice of AE treatment at some sites was discussed during Stage 1, but limited examination of best practice of other RTA ALPSYS® sites was available at that time. Information gathered by the project team is illustrated below in Figure 5. Of the two strategies illustrated, the first is not suitable for TAC with very slow beam movements and still utilizes large up orders in each loop that were discredited in Stage 2. The second strategy is more closely aligned to the best practice in the RTA Pacific region and fits well with the findings from Stage 2.

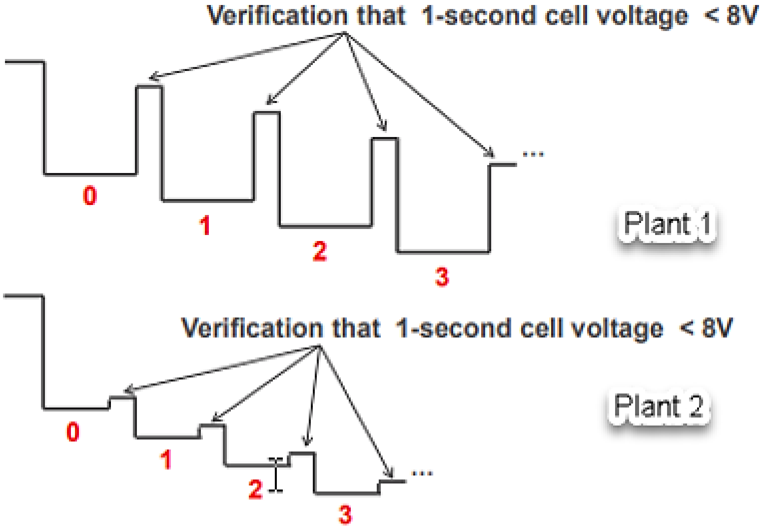


Figure 5. Different AE treatment philosophies.

Applying the benchmarking [1] and Stage 2 learning within the control system constraints at Tomago, Figure 6 illustrates the revised proposal with the following features:

- Preliminary loop down order as per Stage 2
- Minimal up orders in preliminary and elementary loops
- 4 elementary loops, each with a single down order only
- Extended hold time after the preliminary and elementary loops
- Shallower maximum depth
- Shorter duration to reach impossible declaration for maximum loops.

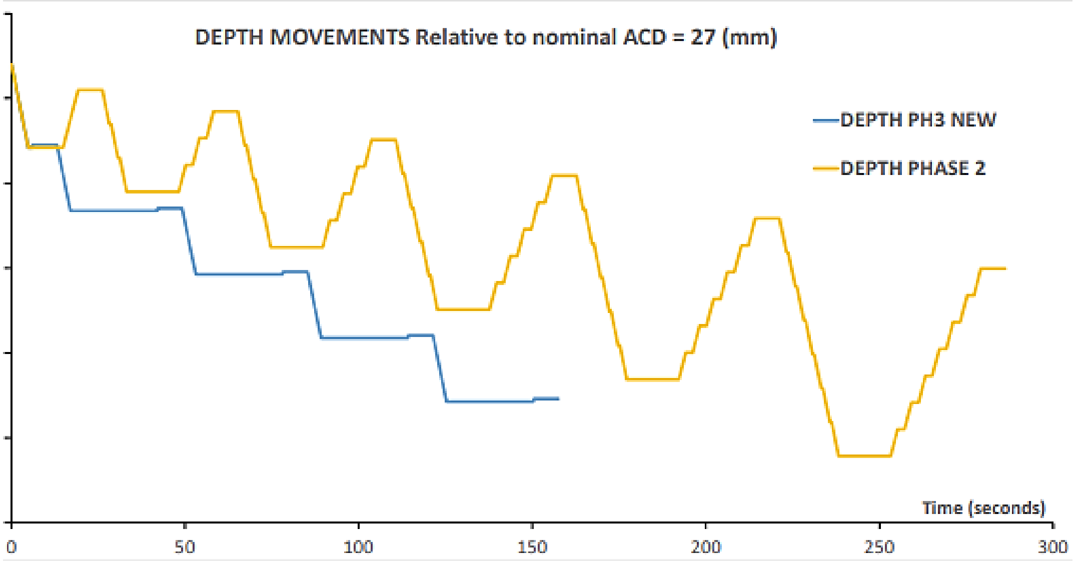


Figure 6. Revised stage 3 proposed trial AE treatment.

6.2 Risk Assessment and Proof of Concept

The parameter changes were tested and reviewed by the project team in France. After minor refinement, the overall scheme was assessed as sound. The final phase of the risk assessment was agreed as a proof-of-concept test on 5 cells each on Line 1, 2 & 3.

The trial parameter settings were tested from 4 October 2023. A typical example indicating that the adjustment phase was too fast is shown in Figure 7, where the AE voltage was extinguished by the preliminary loop, but then returned during the adjustment phase, requiring elementary loop 1. The expansion to a full trial was requested for 18 October 2023.

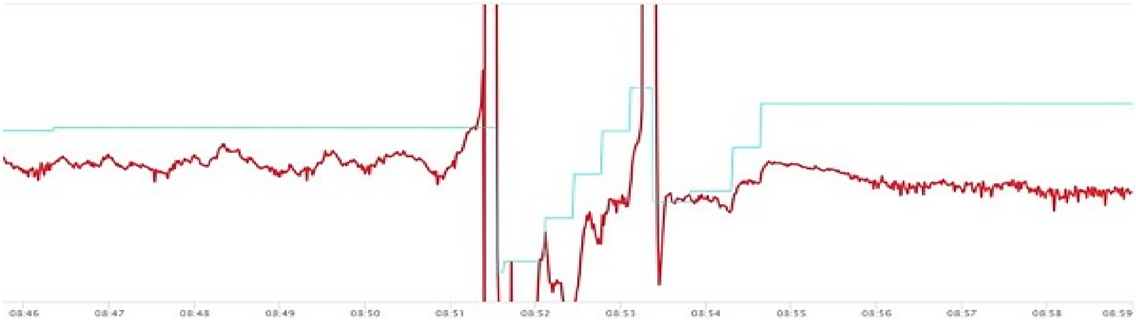


Figure 7. Proof of concept 1-second logging example.

6.3 Trial Set-Up and Results

The Stage 3 trial was conducted on 1 work section per potline between 18 October and 10 November 2023 (1 anode rota). The trial sections were groups AG3, CG3 and EG3.

Individual Before, After, Control, Interaction (BACI) [2] analysis was set up for each trial section to assess the impact on each line:

- Line 1: AG3 (A093-A140) trial group with AG1 (A001-A048) control group
- Line 2: CG3 (C093-C140) trial group with CG1 (C001-C048) control group
- Line 3: EG3 (E093-E140) trial group with EG1 (E001-E048) control group.

The impacts on each line were similar, though Line 2 impact was less significant, starting from a better baseline.

Figures 8–11 showed promising results which were impacts of these parameter changes:

- Very highly significant reduction in seconds > 8 V (27 seconds per AE). The reduction in time above 8 V, which is directly related to PFC generation, is 27 s/AE, which is more than a 50 % reduction.

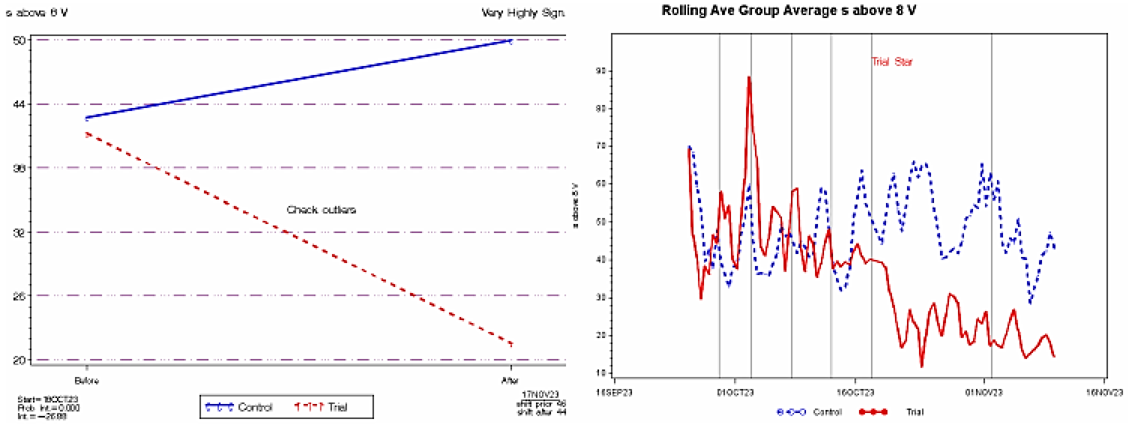


Figure 8. BACI/Run charts for seconds > 8 V.

- Very highly significant reduction in AE overvoltage (6.56 units per AE as recorded by ALPSYS®). This reduction in AE overvoltage, which is also directly related to PFC generation, is more than a 60 % reduction and fully expected given the reduction in seconds > 8 V.

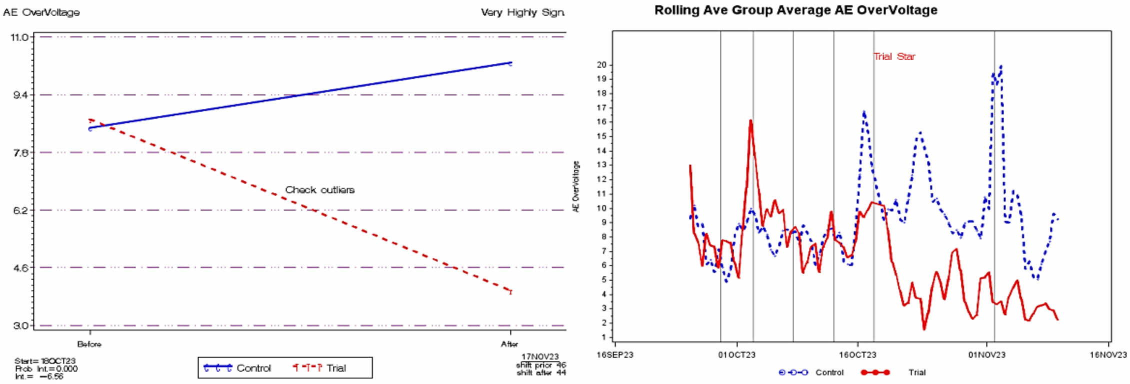


Figure 9. BACI/Run charts for AE overvoltage.

- Highly significant reduction in impossible AE rate (0.022 per cell per shift). The reduction in Impossible AE loops is numerically small, but in percentage terms is > 75 %, which is a significant contributor to the previous results and requires far less interventions by the shift crews.

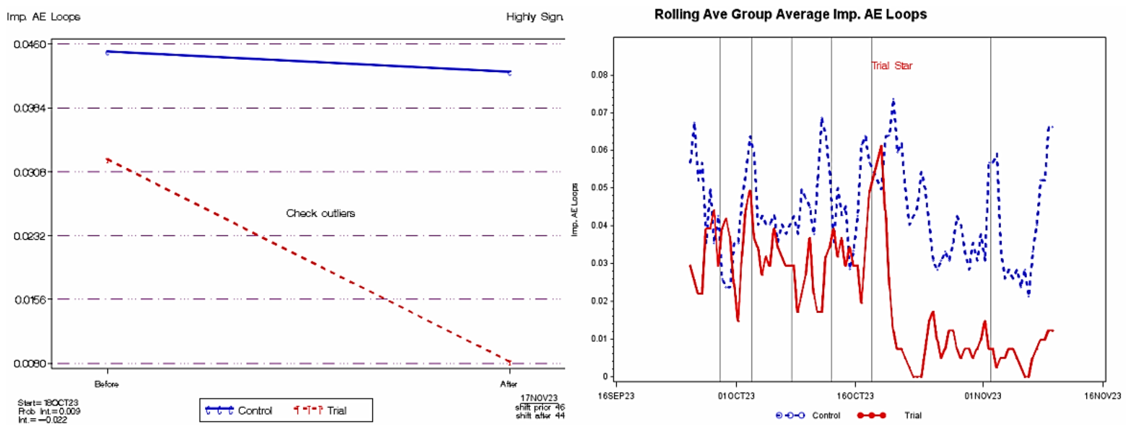


Figure 10. BACI/Run charts for impossible AE rate.

- Almost significant reduction in cells with multiple AE on a shift. This reduction is small and less visible on the run chart, though it is almost statistically significant, and is an encouraging sign that the Stage 3 settings may reduce the risk of more AEs from feeder blockages by displacing less bath.
- There was a non-statistically significant decrease in AE frequency, which though small, also correlates well with the reduction in multiples and is not illustrated here.

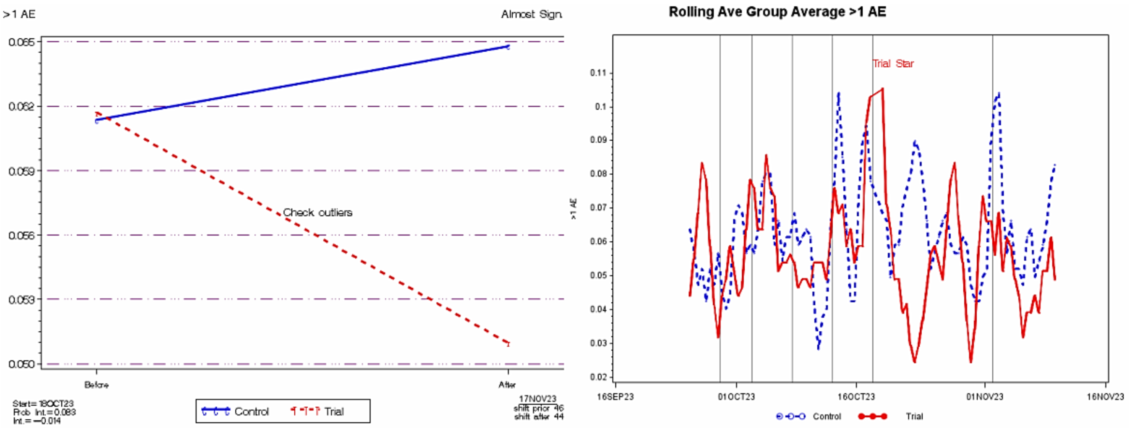


Figure 11. BACI/Run charts for multiple AE.

7. Stage 3 Roll Out and Results

With successful improvement demonstrated by the trials, it was recommended and agreed for immediate adoption on all cells. The full implementation to all cells was deployed on the 15th November.

Figures 12 and 13 show a clear step change in estimated PFC emissions after the roll out of stage 3 settings. Figure 14 shows that improvements were sustained.

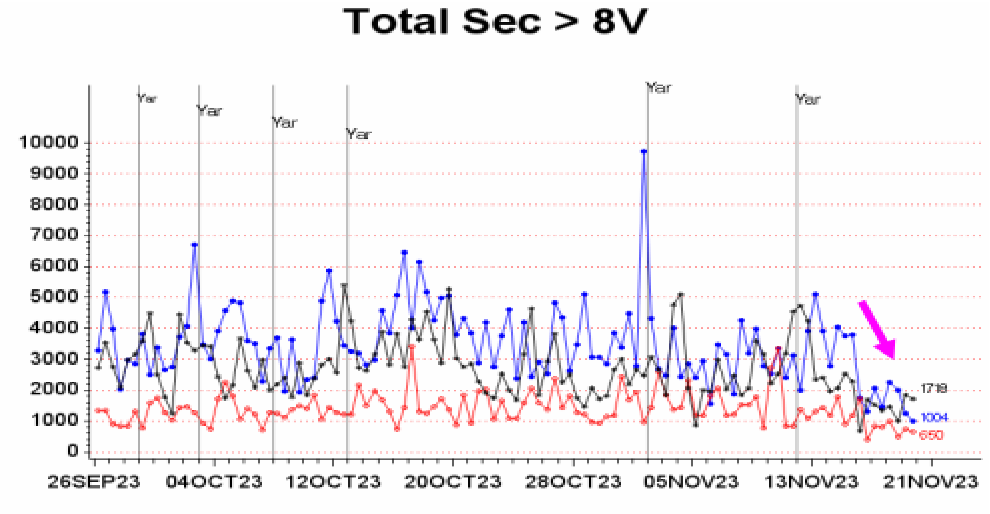


Figure 12. Run charts for seconds >8 V (one line per potline).

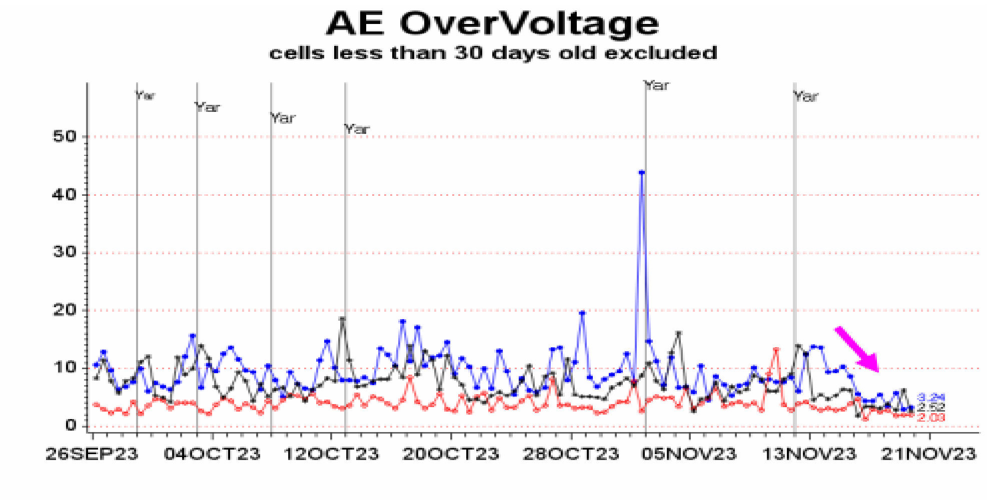


Figure 13. Run charts for AE overvoltage (one line per potline).

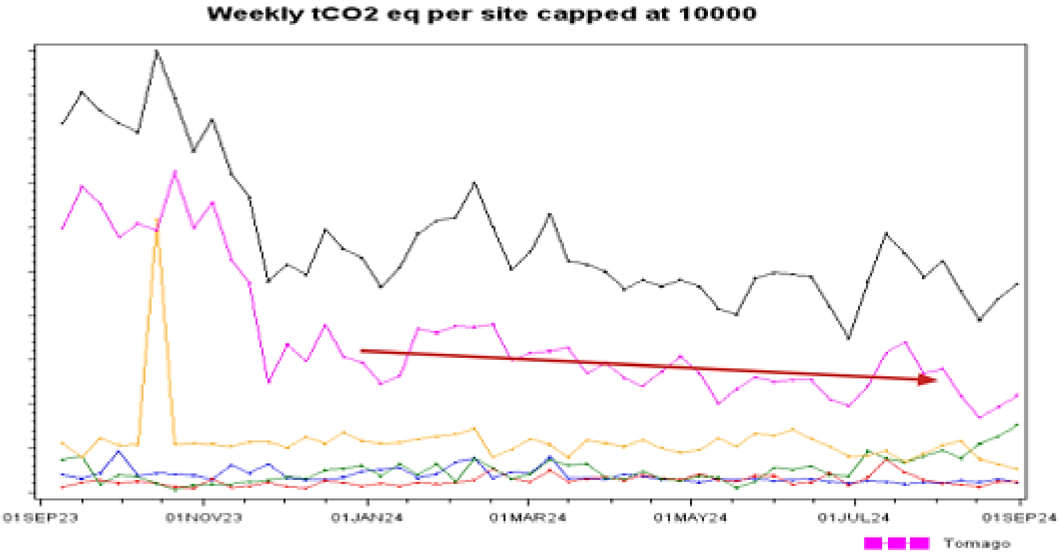


Figure 14. Run charts for t CO_2 equivalent.

Figure 15 shows the improvement in AET kill rate in Loops 0 and 1 to 80–85 % compared with 50–62 % before the start of Stage 1.

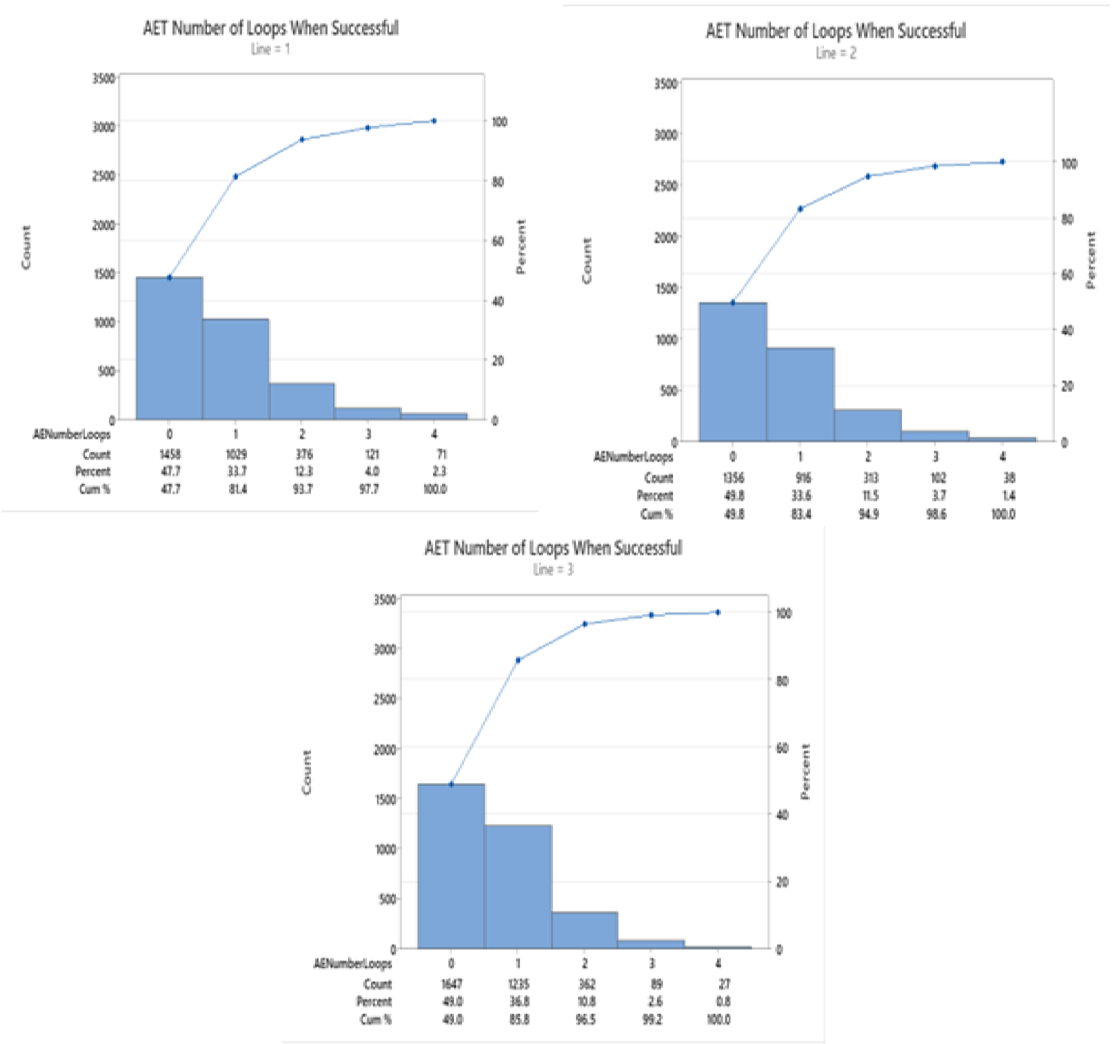


Figure 15. Successful AE terminations by loop number with stage 3 (all lines).

Anode Effect treatment at TAC has significantly improved with statistical confidence using best-practice methodology to set treatment parameters. The specific outcomes demonstrated were:

- Potential for 50 % reduction in time above 8 V and > 50 % reduction in AE overvoltage.
- Significant reduction in Impossible AE declarations.

These outcomes have reduced the estimated PFC contribution from TAC by at least 50 % even though there is no significant change in anode effect frequency directly from this work.

8. Conclusions

1. Observed consistent reduction of more than 50 % PFC's through implementation of the settings tested in stage 3. These results have been sustained to date.
2. A systematic approach to modifying these underlying mechanisms in the cell helped to address the associated risks at the right time. This approach provided confidence in conducting large trials.

3. The success of the Stage 3 trial using several work sections and covering all potlines illustrates the value and power of large trials to prove (or disprove) an opportunity quickly. This success was highly significant and was assessed within a single anode rota enabling us to get the maximum benefit quickly.
4. This trial has re – confirmed the findings since then that squeezing ACD and holding is more effective than progressively deeper "loops" to squeeze/un-squeeze the ACD and pump the displaced bath into and out of the channels and feed zones
5. The 3 stages of this improvement work have demonstrated that there is significant risk of AE conditions returning if up orders are processed either too soon after the down orders, or at too fast a rate when trying to recover the cell to target resistance. Minimal up orders during AE treatment are considered best practice, and the rate of adjustment (rehabilitation) needs to be carefully managed once the cell voltage drops.

9. References

1. Andrew Wilson, Mark Illingworth and Mike Pearman, Anode effect prediction and pre-emptive treatment at Pacific Aluminium, *12th Australasian Aluminium Smelting Technology Conference*, Queenstown, New Zealand*,* 2018, Paper 4c3.
2. Stephen L. Rutledge, Techniques to increase the power of the BACI analysis method, *12th Australasian Aluminium Smelting Technology Conference*, Queenstown, New Zealand*,* 2018, Paper 2c3.