Application of Networked Self-Balancing Busbar Technology (NSBT) for MHD Stability Improvement in Aluminium Reduction Cells

Dezan Li[1], Xi Cao[2], Hongwu Hu[3], Xuan Wang[4], Jinlong Hou[5], Ye Kong[6] and Libo Du[7]
1. Deputy Director of Technology Department
Guangxi Hualei New Materials, Pingguo, China
2. Deputy Director of R&D Department
3. Director of Aluminium Electrolysis Department
4, 5. Managers - Cell R&D
6. Senior engineer - Cell R&D
7. Engineer - Cell R&D
Shenyang Aluminium and Magnesium Engineering & Research Institute (SAMI), Shenyang, China
Corresponding author: hhw1979@126.com
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Abstract

Large-capacity aluminium reduction cells face magnetohydrodynamic (MHD) instabilities caused by current distribution imbalances, thermal disturbances, or operational anomalies, leading to anode effects, aluminium liquid oscillations, and stability degradation in adjacent cells via conventional busbar configurations. This study presents a networked self-balancing busbar technology (NSBT) that dynamically redistributes current to restore current distribution equilibrium and suppress MHD fluctuations in real time. The NSBT system mitigates current imbalance propagation, improving local and potline-wide stability. Transient simulation shows a 70 % reduction in current imbalance and 2.66–5.24 % drop, 4.94–7.09 % enhanced uniformity in vertical magnetic field intensity during anode changing and 29 mV decrease in short-circuit busbar voltage. Additionally, the current deviation of after-retrofit in the nearest slot-penetrating busbars following anode replacement was reduced by 36.7–47.13 % compared to pre-retrofit. The technology also isolates faulty cells, preventing upstream/downstream instability (69 % improvement in adjacent cell balance during short circuits). Industrial trials at Hualei Aluminum smelter confirm a 58.3 % reduction in voltage fluctuations, 0.32 % increase in current efficiency, and 56 kWh/t Al energy savings. This innovation enhances the cell resilience to disturbances while achieving significant energy efficiency gains, offering a scalable solution for large-scale aluminium green production.

Keywords: Magnetohydrodynamic stability, Networked self-balancing busbar technology, Current distribution imbalance, Hydrodynamic instability suppression, Anode effect mitigation.

1. Introduction

Due to the high electrical conductivity of the liquid aluminium, the current from upstream cells in potline is distributed through the equipotential body of liquid aluminium, resulting in relatively uniform current outflow from each cathode assembly in the upstream cells. Upon reaching the bath layer of the next cell, the current flowing through each anode assembly remains relatively uniform.

In practical production, fluctuations in aluminium electrolysis cells are inevitable. Whether caused by breakdown of concentration control, thermal balance instability, operational errors, or stochastic factors, these fluctuations fundamentally stem from disruptions in the electrical balance, which subsequently trigger magnetohydrodynamic (MHD) instabilities. Severe MHD fluctuations, such as anode effects or large-scale liquid aluminium oscillations, not only destabilize the affected cell but also propagate disturbances to adjacent cells. This cross-cell interference intensifies with larger current capacities. Empirical observations reveal that severe fluctuations in aluminium electrolytic cells, particularly those impacting neighbouring cells, occur frequently. Compared to normal fluctuations, such events are significantly more challenging to eliminate, require prolonged recovery periods, and result in greater operational and economic losses.

Our technical team has identified that large-capacity cells frequently encounter the following operational problems: (1) When a single cell experiences an anode effect or abnormal oscillations, adjacent upstream and downstream cells are affected to similar instabilities and oscillations. (2) Reduced stability occurs following anode replacement operations. (3) Adjacent cells exhibit lower stability when a single cell shut down. These issues arise due to disruptions in the electrical balance of the cell, which exceed the deviation correction capabilities of conventional busbars [1].

Conventional electrolytic cells employ a cathode busbar block configuration that relies solely on two equipotential surfaces: the anode busbar and the liquid aluminium layer. Under normal operation, this design prevents interference between upstream and downstream cells. However, when a cell becomes unstable, the block busbar structure lacking equipotential properties fails to correct current distribution deviations caused by liquid aluminium fluctuations. Consequently, current oscillations from the unstable cell propagate through busbars to adjacent cells. This cross-cell interference intensifies with higher current capacities. This phenomenon is described as mutual interference between adjacent cells in large-scale electrolysis systems, which can trigger instability ripple effects. Self-balancing network busbar technology has emerged as a critical solution.

NSBT establishes a new equipotential surface through its non-block configuration, effectively recalibrating current distribution deviations caused by liquid aluminium fluctuations. This design blocks mutual interference between upstream and downstream cells, thereby resolving instability ripple effects. Additionally, it significantly mitigates the propagation of cathode/anode current distribution imbalances during unstable cell states such as shutdowns, anode effects, or after-anode replacement across the electrolysis series. By suppressing current distribution irregularities and magnetic field fluctuations in both unstable cells and their adjacent units, this system enhances that MHD stability, operational robustness and disturbance resistance. Consequently, this technology reduces anode effect duration and PFC emission factor while lowering greenhouse gas emissions [2–3].

This technology faced implementation barriers due to busbar welding requirements under normal operating conditions, which conventional equipment could not perform, limiting retrofits to series construction phases or full power shutdowns. However, our GS-220 high-speed welding system for strong magnetic fields, developed in collaboration with Wuhan University enables welding operations unaffected by intense electromagnetic environments. This innovation permits in-situ online upgrades of in-service electrolysis cells.

This thesis evaluates the effectiveness of in-situ NSBT upgrading, and analyzes simulated computational results and production metrics before and after the non-interruptive retrofitting of a 500 kA electrolysis potline. The findings aim to provide a reference for industry peers globally.

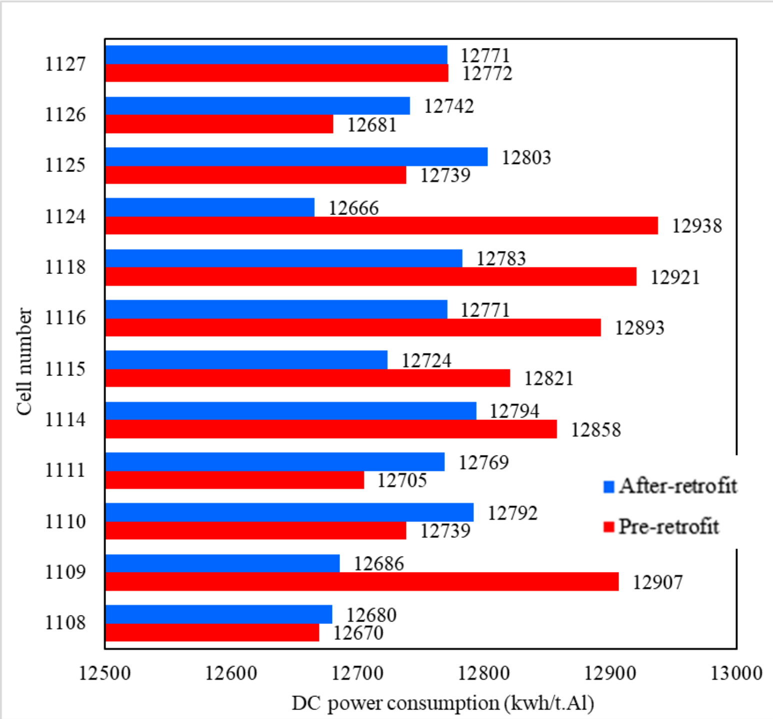

Figure 12. DC power consumptions before and after retrofit.

6. Conclusions

Through analysis of computational results and production metrics before and after the non-interruptive retrofitting of the in-situ MHD stability upgrade technology with networked busbars in a 500 kA electrolysis potline, the following conclusions are drawn:

- The technology effectively recalibrates current distribution deviations caused by liquid aluminium fluctuations, blocks cross-cell interference, and resolves ripple effect of cell oscillations.
- The stability of the electrolysis cells has been significantly enhanced: the average voltage decreased by 3 mV, the anode effect frequency dropped from 0.168 to 0.127 (achieving a 24.4 % reduction), and the average period of voltage swing shortened from 3 minutes to 1.25 minute (achieving a 58.3 % reduction).
- Prior to implementation, the DC power consumption was 12 804 kWh/t Al. Following the project's completion, this value decreased to 12 748 kWh/t Al, achieving a reduction of 56 kWh/t Al.
- The networked busbar MHD stability in-situ upgrade technology for aluminium electrolysis cells enhances stability, reduces energy consumption, and delivers significant direct economic benefits and effectiveness in reducing carbon emissions.

7. References

1. Xi Cao and Hongwu Hu, Construction of green and low-carbon technology system for aluminium electrolysis under dual carbon background, (Chinese) *Light Metals* 2024, 18–23.
2. Tiejun Wang et al., Low carbon emission technology upgrading industrial pilot of 350 kA pots, *Light Metals* 2024, 730–745. https://doi.org/10.1007/978-3-031-50308-5_93

3. Aiping Zhou et al., Upgrade experiment on MHD stability of 350 kA pot, *Proceedings of 42nd International ICSOBA Conference*, Lyon, France, 27–31 October 2024, *TRAVAUX* 53, 1747–1757.