Upgrade and Application of Anti-Disturbance Busbar Technology in Full-Current Environments with Strong Magnetic Fields

Song He[1], Weifeng Wu[2], Xingyu Yang[3], Yi Yang[4] and Chaohong Yang[5]
1. Vice Director of Department
3. Engineer, Smelter Design
4. Professor Level Senior Engineer
5. Vice Chief Engineer
Guiyang Aluminium and Magnesium Design & Research Institute (GAMI), Guiyang, China
2. Senior Engineer
Shanxi Meixin Industry Investment, Tongchuan, China
Corresponding author: song_he768@chinalco.com.cn
https://doi.org/10.71659/icsoba2025-al081

Abstract

For the long-running aluminium potline suffering from uneven electric field distribution in the busbar system, insufficient magnetohydrodynamic (MHD) stability, and abnormal fluctuations in cells leading to stability deterioration in upstream and downstream cells, the R&D team of Guiyang Aluminium and Magnesium Design & Research Institute (GAMI) developed an online upgrading and application technology for a novel anti-disturbance busbar in full-current environments with strong magnetic field. This technology employs an electromagnetic magnetohydrodynamic (EMHD) simulation coupling platform to model current distribution and dynamic MHD stability in the aluminium potline. The anti-disturbance busbar technology corrects the current distribution in cells, while strong magnetic welding technology enables online upgrading of the busbar system in the aluminium potline. The technology effectively mitigates the impact of transient currents on cell stability and blocks the propagation of current distribution imbalance across the aluminium potline under unstable conditions, significantly improving cell stability and interference resistance. After being applied to a 400 kA cell, this technology achieved an average voltage reduction of 31 mV and a DC power consumption decrease of 101 kWh/t Al, with significantly improved cell stability. It provides a scientifically feasible pathway for the upgrade and optimization of busbar systems in the currently operating aluminium potline.

Keywords: Aluminium electrolysis, Current distribution in cells, Anti-disturbance busbar, Strong magnetic welding technology.

1. Introduction

Aluminium, as the most important metal second only to steel in terms of global production and consumption, plays a pivotal role in modern industry. As the world's largest producer of electrolytic aluminium, China's output in 2024 reached 43.393 million tonnes (according to International Aluminium Institute statistics), accounting for 59 % of the global total, underscoring its dominant position in the global aluminium industry. However, the high energy consumption of the aluminium electrolysis process cannot be overlooked. The sector's annual electricity consumption is about 500–550 TWh, representing 7 % of the nation's total electricity usage. With the advancement of national "dual-carbon" policies and industry requirements for high-quality development, energy saving and carbon reduction in electrolytic aluminium have become the primary direction for the industry's progress [1].

In China, cells operating below 200 kA are being gradually phased out and upgraded to large-scale cells with 500–600 kA, while most cells above 240 kA are undergoing technical upgrades either through potline shutdowns or online retrofits. Currently, 240–500 kA cells account for about 50 % of the domestic total. However, these cells generally suffer from inherent issues leading to higher energy consumption. In recent years, China has widely adopted graphite cathode lining modifications, achieving some improvements in energy consumption. Yet, optimization of busbars and operational stability remains challenging, as construction under strong magnetic fields has persistently hindered advancements in busbar upgrades.

1.1 Busbar Design

The design philosophy, multi-physics coupling simulation software, and auxiliary process methods of long-running potlines lag behind current technological levels, exhibiting inherent multi-field problems. Regarding magnetic field design, the new potline's standards require the four-quadrant Bz average value to be within 4 G [2], whereas older potline generally exhibit higher Bz values. Figure 1 shows the composite Bz average distribution in one quadrant:

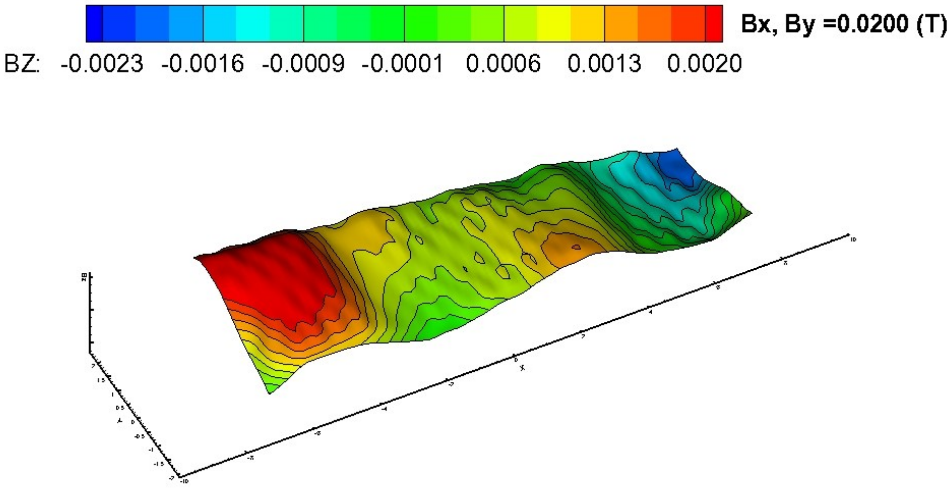

Figure 1. Vertical magnetic field (Bz) distribution of a 300 kA aluminium reduction cell (elevated mean values and gradients).

In terms of current distribution design, the older potline generally prioritized low investment with no requirements for energy consumption. This led to the widespread selection of smaller busbar cross-sections, higher current density in the busbars, and operating no-load voltages consistently higher than current design standards. Additionally, the current distribution uniformity failed to meet today's design criteria.

1.2 Fluctuation Interference Issue Between Cells

In traditional designs, to facilitate electrical balance, multiple conductive paths between the cathode flexibles and the anode risers are separated. However, in production practice, interference fluctuations between adjacent cells have persistently troubled operations, particularly in 400 kA and larger-amperage cells. The cause of interference between cells is that the potline current encounters certain resistance when transmitted through the busbar system of aluminium reduction cells. The obstructed current is forced to redistribute through the molten aluminium, leading to intensified MHD instability issues. This phenomenon becomes particularly pronounced during anode effects or the initial stage of anode replacement, when some anode carbon blocks barely conduct electricity. This results in severe uneven distribution of cathode and anode currents in the cell, which propagates to upstream and downstream cells through the busbar system, deteriorating their MHD stability. Consequently, the cells experience oscillations, adversely affecting production and energy consumption [3].

1.3 Construction Challenges in Strong Magnetic Environments

After the potline is energized and put into operation, the busbars generate a strong magnetic field that surrounds the cells and the plant. According to the author's magnetic field measurements of a 240 kA potline, the average magnetic field around the busbars is approximately 300 G, with peak values reaching up to 550 G. Under such conditions, performing localized optimization on the busbars is extremely difficult. Traditional aluminium TIG welding machines can still achieve acceptable welding quality with certain shielding measures in environments below 100 G. However, in the intense magnetic field surrounding the cells, conventional welding methods fail to meet construction requirements [4].

2. Upgrade Technology of Anti-Disturbance Busbars in Full-Current Environments with Strong Magnetic Fields

The needle-type potline often suffers from issues such as uneven current distribution and poor magnetohydrodynamic (MHD) stability, leading to elevated cell voltage and high black potline voltage values. Additionally, anode replacement or anode effects in upstream cells frequently cause significant voltage fluctuations in downstream cells, adversely affecting the stable operation of the electrolysis cells. The research team of GAMI developed an anti-disturbance busbar upgrade technology for strong magnetic field environments. This technology utilizes a cloud-based electromagnetic-fluid simulation coupling platform to simulate and analyse current distribution and dynamic MHD stability in a potline. Through field testing and iterative calculations, the anti-disturbance busbar technology is employed to recalibrate the current distribution in cells. Additionally, strong magnetic welding technology is applied to achieve online upgrades of the busbar system in the potline. This technology effectively mitigates the impact of transient currents on cell stability and prevents the propagation of current distribution imbalance across the potline under unstable conditions, significantly improving cell stability [5, 6]. It enhances the anti-interference capability of cells while reducing the voltage drop of the busbars through flexible upgrades in areas with high local current density. This approach optimizes electrical balance distribution and provides a practical, systematic technical retrofit solution for online busbar upgrades in older potlines. The core components of this technology include a cloud-based EMHD simulation coupling platform, anti-disturbance busbar technology, and optical-magnetic welding technology for strong magnetic field environments.

2.1 Cloud-based EMHD Simulation Coupling Platform

The cloud-based EMHD simulation coupling platform has established an cell simulation system with full-cycle analysis of electric and magnetic field data [7]. This system adopts the "Cloud-based Intelligent Design Platform for Aluminium Reduction Cells" independently developed by GAMI as the solution and modelling platform. Using Ansys® 2020R1 and Valdis MHD as analysis tools (as shown in Figure 2), it rapidly constructs models through cloud-based design parameter inputs. By performing electromagnetic coupling calculations, it evaluates magnetic field distribution, electrical balance, and MHD dynamic stability. The platform further integrates testing devices such as optical-magnetic current testers and Gauss meters to iteratively optimize simulation results with measured data. This process accurately identifies MHD and electrical balance issues in operating potline and formulates targeted optimization solutions, ultimately providing customized busbar upgrade and modification plans for operational potlines.

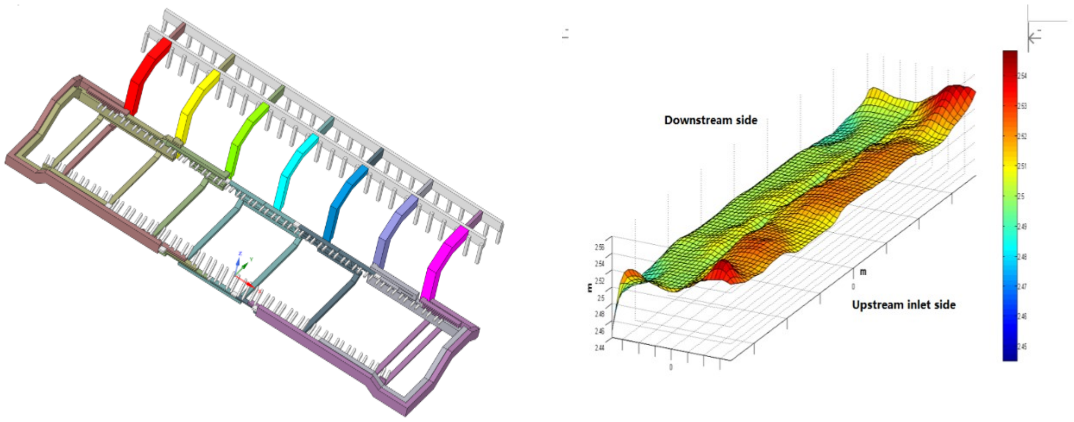

Fig. 2. Cloud-based EMHD simulation coupling platform.

2.2 Anti-Disturbance Busbar Technology

In the electrical balance design of conventional busbars, multiple conductive paths between the cathode flexibles and the anode risers are isolated from each other, as illustrated in the circuit schematic diagram (Figure 3).

When localized fluctuations or anode effects occur in an cell, the current distribution becomes disrupted. This uneven current distribution propagates to adjacent upstream and downstream cells. Particularly in cells with the amperage higher than 400 kA, during anode effects or early-stage anode replacement, some anode carbon blocks barely conduct electricity, leading to a severe imbalance in cathode and anode current distribution. This imbalance is transmitted through the busbar system to upstream and downstream cells, deteriorating their magnetohydrodynamic stability and causing oscillations [8, 9].

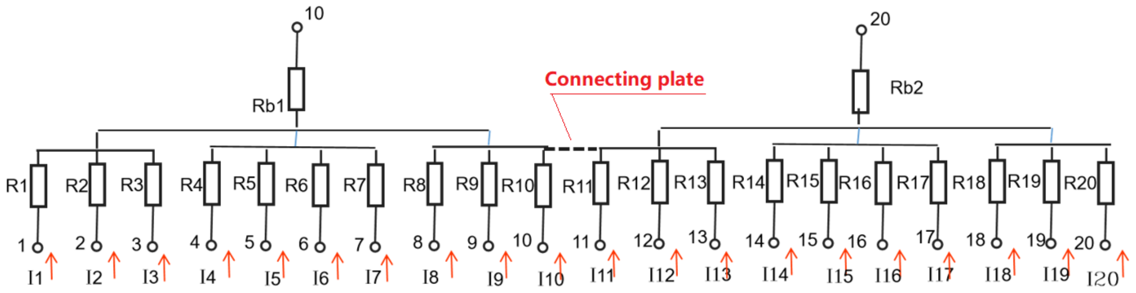

Figure 3. Traditional busbar solution (branch busbars to anode riser section) and connecting plate location.

The anti-interference busbar technology installs a connecting busbar at the cathode branch busbars to form multiple electrical bridges, while ensuring equipotential at the outlet of the branch busbars. This design maintains a consistent current distribution in the busbars regardless of fluctuations in the cell current. The circuit schematic is shown in Figure 4.

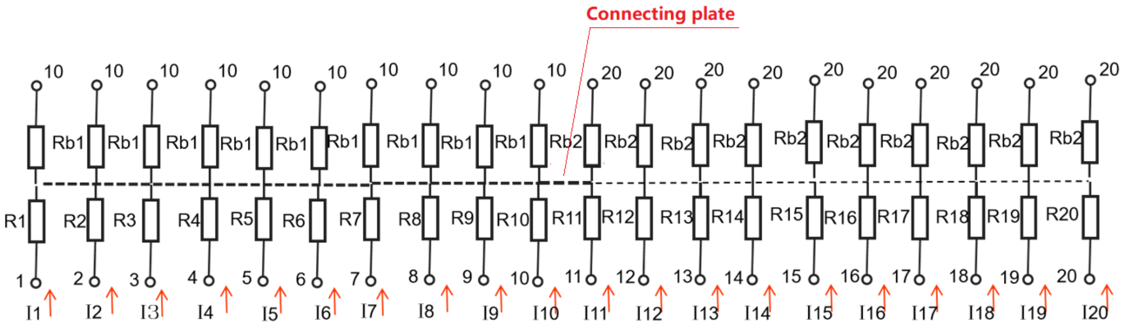

Figure 4. Traditional busbar solution (branch busbars to anode riser section) and connecting plate location.

This technology forms equipotential surfaces on the busbars of each layer on Side A and Side B respectively, creating an equipotential on the cathode busbars of the cell. This suppresses horizontal currents generated by the deformation of the molten aluminium / electrolyte interface, thereby significantly improving the MHD stability of the cell.

Using dynamic MHD stability analysis software for cells, a comparative calculation was performed between traditional busbar designs and those employing the anti-disturbance busbar technology. The results are shown in Figures 5–6.

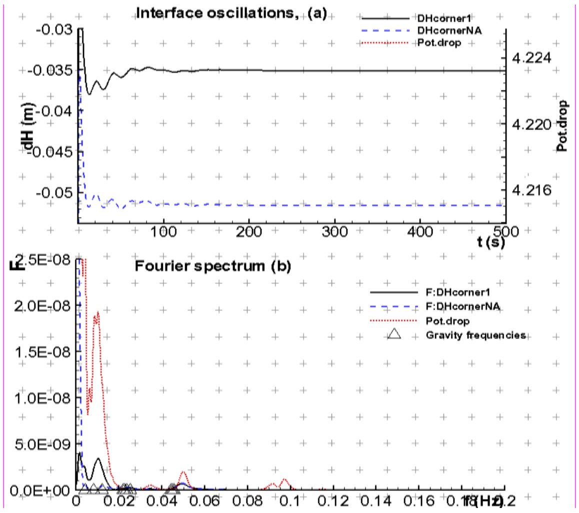

Figure 5. Calculation results of traditional busbar scheme.

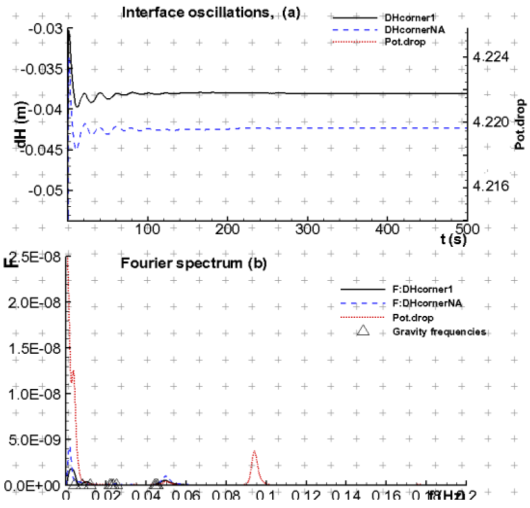

Figure 6. Calculation results of anti-disturbance busbars.

Through comparative analysis, the traditional busbars exhibit significant voltage fluctuations, with a stabilized voltage of 4.224 V and a fluctuation duration of 150 s. After applying the anti-disturbance busbar technology, the stabilized production voltage decreases by approximately 10 mV, the recovery time after fluctuations is reduced from around 150 s to 100 s, and the maximum fluctuation amplitude is reduced by about 40 %.

2.3 Optical-Magnetic Welding Technology in Environments with Strong Magnetic Fields

The construction of busbar systems in strong magnetic fields has long been a challenge, restricting the renovation of the potline busbars. Traditional TIG welding machines struggle to achieve the designed welding quality due to arc blow and other issues in environments with strong magnetic fields. While magnetic suppression devices could theoretically address this, their complex installation and low construction efficiency make them impractical for engineering applications. Consequently, HAMI has developed an optical-magnetic welding technology for environments with strong magnetic fields. This laser-based anti-magnetic welding solution maintains welding quality even in 1000 G fields without requiring additional magnetic suppression equipment.

Currently, online welding has been implemented on the 600 kA cell type, with welding speed and penetration depth comparable to traditional TIG welding, ensuring both construction efficiency and quality. The application of this technology makes online renovation of the potline busbar system possible. The post-welding quality is shown in Figure 7.

Figure 7. Welding effect diagram of optical-magnetic welding technology.

3. Project Implementation and Results

The technology has now been applied in 200–600 kA cells. In 2024, the team conducted an online upgrade of a 420 kA cell using the anti-disturbance busbar technology. First, a cloud-based MHD simulation coupling platform was employed to establish a model, followed by a dynamic multi-physics field simulation analysis. The current fluctuations were calculated for both the original busbar configuration and the upgraded anti-disturbance busbar configuration during corner anode replacement. The modelling and computational results are illustrated in Figures 8 and 9.

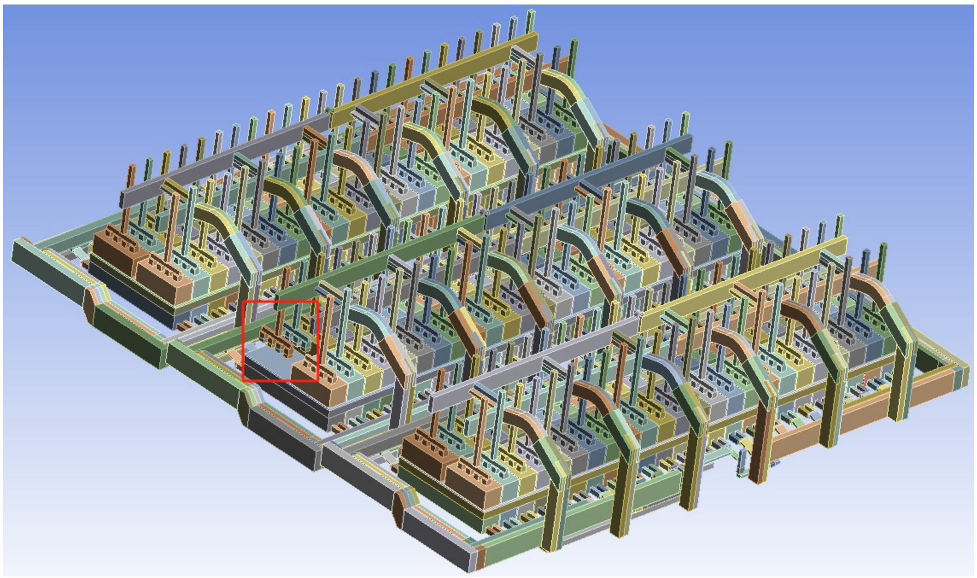

Figure 8. 3D simulation model of 420 kA cell busbars.

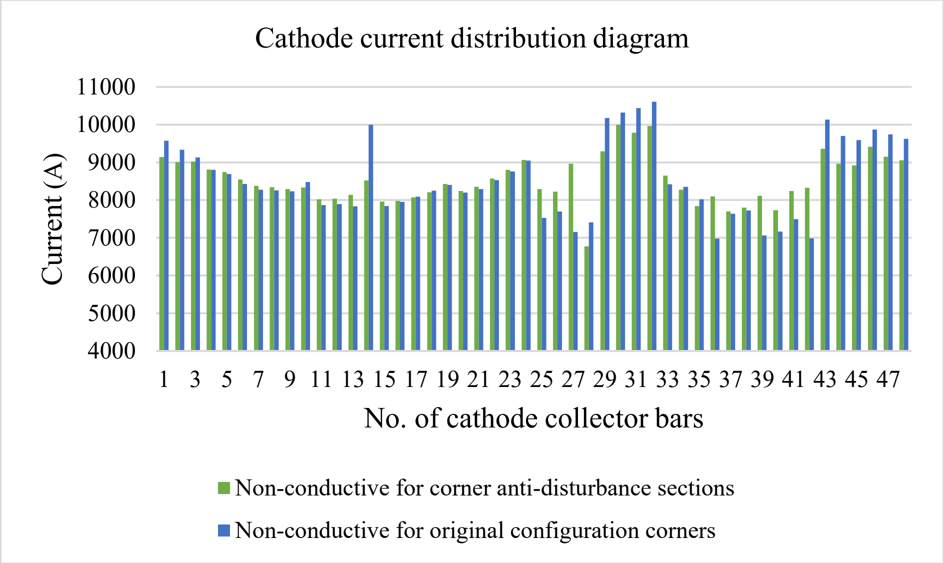

Figure 9. Calculation of cathode current distribution.

A comparison of the mean current fluctuation percentages between the two models shows that the anti-disturbance busbar configuration exhibits smaller cathode current fluctuations under the unstable non-conductive condition during corner anode replacement. As presented in Table 1, the mean cathode current fluctuation percentage is reduced by 3.87 % with the anti-disturbance busbar configuration.

Table 1. Comparison of mean cathode current fluctuation percentages under non-conductive corner operation conditions.

Model	Operating conditions	Mean percentage of current fluctuation
Anti-disturbance busbars	Corner anode replacement	5.78 %
Original configuration busbars	Corner anode replacement	9.65 %

By adopting anti-disturbance busbar technology, both Side A and Side B were connected as equipotential bodies, and no-cell-outage construction was performed using optical-magnetic welding technology. The construction quality met design requirements in the environment with a strong magnetic field, without disrupting normal production, as shown in Figure 10.

Figure 10. Welding quality of 420 kA optical-magnetic welding machine during construction.

One month after the completion of construction and stable operation of the test cells, the effectiveness of the anti-disturbance busbar technology was analysed based on voltage curves and actual production data. In terms of voltage curves, as shown in Figure 11, Cells 1433# and 1434# were equipped with the anti-disturbance busbar technology. When Cell 1434# experienced voltage fluctuations and anode effects, Cell 1433# remained almost unaffected by the voltage fluctuations or anode effects from Cell 1434#, demonstrating that the anti-disturbance busbar technology effectively eliminated the impact of anode effects on adjacent cells. In contrast, as shown in Figure 12, Cells 1417# and 1418# did not adopt this technology. When Cell 1418# underwent an anode effect, Cell 1417# also exhibited a certain degree of voltage fluctuation.

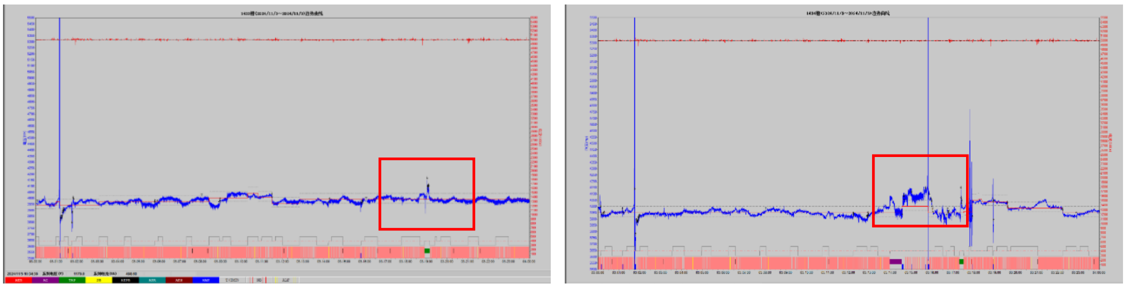

Figure 11. Voltage fluctuation in test cell with anti-disturbance busbars.

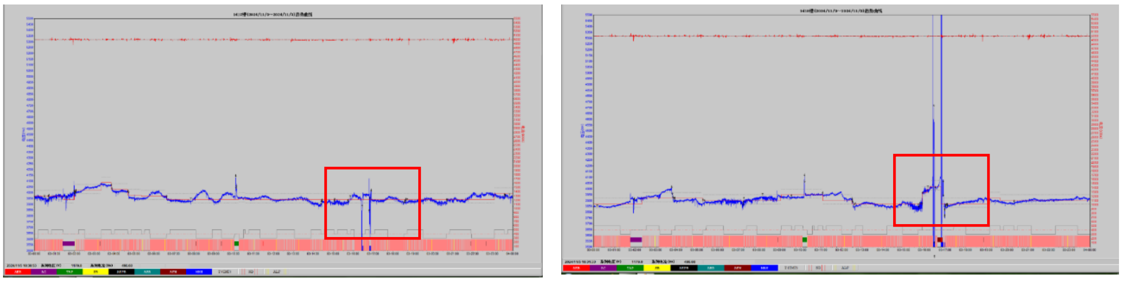

Figure 12. Voltage fluctuation in test cell with conventional busbars.

A comparative analysis of production data from test cell 1434# before and after its modification is presented in Table 2.

Table 2. Process parameters and economic indicators of test cell.

Cell No.	Set voltage (V)	Average voltage (V)	Current efficiency (%)	DC power consump-tion (kWh)	Overall effect coefficient	Aluminium level (cm)	Noise (mV)	Obs.
3319#	3.890	3.895	91.35	12 706	0.194	24	21	3-month average before retrofit
3319#	3.870	3.864	91.35	12 605	0.129	24	15	One-month after retrofit
YoY	-0.020	-0.031	0	-101	-0.065	0	-6	

For production process data collection, after implementing the anti-disturbance busbar technology upgrade, the operating voltage decreased by 20 mV, the average voltage dropped by 31 mV, and the anode effect frequency reduced by 0.065 AE/cell·day. The noise value decreased by 6 mV, while DC power consumption lowered by 101 kWh/t Al. Post-anode replacement fluctuations and post-tapping cell disturbances significantly decreased. Mutual interference between neighbouring cells during anode effects was effectively mitigated, with smoother curve operation and a notable reduction in anode effect occurrences. The shared voltage during anode effects also declined, contributing to a marked reduction in DC power consumption.

4. Conclusions

For operating potlines suffering from issues such as uneven current distribution, poor MHD stability, and voltage fluctuations in downstream cells caused by anode replacement or anode effects in upstream cells, affecting overall stability, our team developed an upgraded anti-disturbance busbar technology for environments with a strong magnetic field. This technology employs a cloud-based coupled EMHD simulation platform to conduct dynamic stability analysis of existing older plotlines. By implementing anti-disturbance busbar technology, interbus is installed on the cathode busbars to form multiple electrical bridges, while ensuring equipotential conditions at the branch busbar outlets. This significantly enhances the cells' anti-disturbance capability and improves operational stability. Additionally, optical-magnetic welding technology for environments with strong magnetic fields is adopted to enable online construction without shutting down the cells. The technology has been successfully applied in multiple 200–600 kA potlines. After the pilot retrofit of a 400 kA cell, the average voltage was reduced by 31 mV, with DC power consumption decreasing by 101 kWh/t Al, alongside notable improvements in operational stability. Practice has proven that this technology provides a scientifically viable approach for upgrading and optimizing busbars in currently operating potlines, offering smelters a practical solution for energy saving and carbon reduction.

5. References

Yanbin Wang, Current Status of Carbon Emissions in the Electrolytic Aluminium Industry and Pathways for Energy Conservation and Carbon Reduction, *Resources Economization & Environmental Protection*, No. 2, (2025), 14–19, https://doi.org/10.16317/j.cnki.12-1377/x.2025.02.027 (in Chinese).
Xuemin Liang, Discussion On the Busbar Design of Modern Large Aluminium Reduction Cells, *Light Metals*, No. 1, (1990), 20–26, https://doi.org/10.13662/j.cnki.qjs.1990.01.009 (in Chinese).
Xiaodong Yang, Discussion on Designing High Amperage Energy-saving Aluminium Reduction Cells - Busbar, Cathode Structure and MHD Stability, *Light Metals*, No. 10, (2016), 27–32, https://doi.org/10.13662/j.cnki.qjs.2016.10.006 (in Chinese).
Yiqing Liu, Influence of Magnetic Field on Welding and Anti-magnetic Welding in Aluminum Smelter, *Light Metals*, No. 3, (1978), 14–18, https://doi.org/10.13662/j.cnki.qjs.1978.03.004 (in Chinese)
Min Huang, Stability Analysis and Flow Field Calculation of Magnetic Fluid in Aluminium Reduction Cells, Wuhan: Huazhong University of Science and Technology, 2002 (in Chinese).
Nobuo Urata, Wave Mode Coupling and Instability in the Internal Wave in Aluminum Reduction Cells, *Light Metals*, 2005, 455–460 (in Chinese).
Yi Yang, Determination Criteria for Magneto-Hydro-Dynamics Stability of Aluminium Reduction Cells: Research Based on Arithmetic Mean Value of Bz, *Nonferrous Metals (Extractive Metallurgy)*, No. 01, (2025): 66–71, https://doi.org/10.20237/j.issn.1007-7545.2025.01.009 (in Chinese).
Xiang Nie, et al., *Electromagnetic Field and Electromagnetic Waves*, Xi'an: Xi'an Jiaotong University Press, 2022 (in Chinese).
Tingyang Zhou, Hongyan Zhang, *Electrical Network Theory*, Hangzhou: Zhejiang University Press, 1997 (in Chinese).