Application of RuC Technology in 600 kA Aluminium Reduction Cells

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Abstract

The ready to use cathode (RuC) technology has transformed the cathode assembly method, and by optimizing the cathode structure and upgrading the collector bar material, the average horizontal current in the aluminium pad has decreased by nearly 70 % compared with conventional cathode structure with steel collector bars, which significantly improved the magnetohydrodynamic (MHD) stability of the aluminium reduction cell. The cathode voltage drop (CVD) of the 600 kA RuC cell is about 150 mV, which is 50–100 mV lower than in conventional cathode cell, and the CVD of RuC cells is relatively stable for a long time. High MHD stability and low CVD create favourable conditions for stable and efficient operation of the reduction cell at low voltage.

By the end of December 2024, RuC technology has been applied in more than 110 aluminium reduction cells in Weiqiao 600 kA potlines, with of the oldest cells of 4.5 years. The cells operate smoothly and efficiently with excellent key performance indicators (KPIs). The cell voltage is 3.86–3.90 V, the current efficiency exceeds 94 %, and the DC energy consumption is about 12 300 kWh/t Al. Based on cathode wear measurements, the expected cell life will be significantly longer than in conventional cells. The application of RuC technology will be further expanded in Weiqiao smelters.

Keywords: Ready to use cathode (RuC), 600 kA aluminium reduction cell, Low energy consumption, High current efficiency, Long cell life.

1. Introduction

China is actively adopting stronger policies and measures towards carbon neutrality. In accordance with dual carbon goal, to reach carbon peak before 2030 and carbon neutrality by 2060, announced by President Xi Jinping on UN General Assembly on 22 September 2020, several pledges towards this goal have been announced, such as:

"By 2030, China's carbon dioxide emissions per unit of GDP will drop by more than 65 % compared with 2005, the proportion of non-fossil energy in primary energy consumption will reach about 25 %, the forest stock will increase by 6 billion cubic meters compared with 2005, and the total installed capacity of wind and solar power will reach more than 1.2 billion kilowatts." [1].

Aluminium is the most widely produced non-ferrous metal in the world, with nearly 60 % of primary aluminium produced in China, according to International Aluminium Institute

statistics [2]. Aluminium reduction is a major consumer of electricity, consuming more than 580 TWh of electricity, accounting for approximately 7.5 % of China's total electricity consumption. Electrolytic aluminium carbon dioxide emissions account for about 75 % of the total emissions in the non-ferrous metal industry and about 3.5 % of the total carbon dioxide emissions in China.

In 2024, China's primary aluminium production reached 43.396 million tonnes [2]. The peak production capacity of primary aluminium has become one of the key industries for carbon emissions peaking. According to [3]:

"In recent years, the national supply side reform has achieved {good} results, with limited increase in production capacity on the supply side, increased demand for clean energy aluminium on the demand side, and tight supply and demand leading to an aluminium per tonne high profit market."

With the deepening implementation of the national "dual carbon" strategy and related industrial policy requirements, the electrolytic aluminium industry is facing a challenge of reducing carbon dioxide emissions. Accelerating the key technology research and major demonstration project construction for energy-saving and carbon reduction in electrolytic aluminium is the important task for the survival and development of smelters. Based on the requirements of government policies, starting from 2025, the comprehensive AC power consumption of liquid aluminium has to be lower than 13 300 kWh/t Al (excluding desulfurization power consumption). Chinese aluminium reduction companies are actively searching for technologies and ideas to further reduce aluminium reduction energy consumption.

2. Research and Development of Energy-Saving and Low-carbon Technologies in China

"Since entering the new century, China has made significant progress in the core technology of primary aluminium, with internationally leading technology for high amperage cells. 600 kA aluminium cell technology has been widely applied, and the average energy consumption per unit product has shown a significant downward trend overall." [3]

In 2024, the industry's average comprehensive AC power consumption was about 13 400 kWh/t Al, a decrease of 600 kWh/t Al compared to 2013.

In recent years, under the requirements of the national "dual carbon" emissions policy, the research and technology development in China's aluminium reduction industry have developed energy-saving technologies for the cathode structure of aluminium reduction cells, such as graphitized cathode blocks, large cross-section high conductivity collector bars, copper insert collector bars, etc., which have achieved varying degrees of energy-saving in different application scenarios [3].

3. RuC Technology Research and Application in China

In order to achieve further energy saving and carbon reduction, Shandong Weiqiao group, NEUI, Tokai COBEX and NFC collaborated to develop the "RuC energy-saving, long life, and high yield aluminium technology" with Tokai COBEX patented ready to use cathode (RuC) technology as the core [4, 5].

The RuC stability in cathode voltage drop (CVD) with low electrical contact resistance is achieved despite the lower contact surface area between the collector bar and carbon block (-60 %) compared to conventional cathodes. The low level and stable trend of CVD proves the robustness of the cathodic system [6].

Due to excellent electrical conductivity of RuC, the simulated voltage drop of the 600 kA RuC cell is 149 mV shown in the Figure 1, which is much lower than the conventional cathode structure with steel collector bars, creating favourable conditions for stable and efficient operation of the reduction cell at low working voltage.

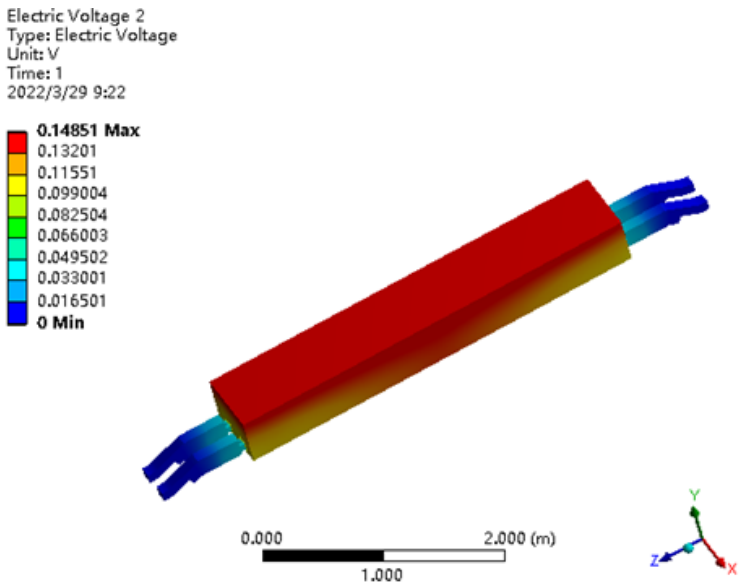

Figure 1. Cathode voltage drop simulation result of 600 kA RuC cell.

This technology has been undergoing industrial trials on NEUI400 and NEUI600 aluminium reduction cells of Weiqiao Group since December 2016, achieving significant energy-saving, production increase, and pot life extension. In order to better respond to the policy requirements of "dual control" of energy consumption and lead industry technological progress, Weiqiao Group (its aluminium subsidiary Hongqiao Group) has started to expand the application of RuC technology in 600 kA potlines [3].

3.1 Key Role of RuC Technology in Improving MHD Stability

The RuC technology has transformed the cathode assembly method, and by optimizing the cathode structure and upgrading the collector bar material with high electrical conductivity, the average horizontal current decreased by 65.3 % compared with traditional cathode structure (Figure 2), significantly reducing the electromagnetic forces in the aluminium pad, slowing down the oscillations of the aluminium pad, widening the effective ACD, greatly improving the MHD stability of the aluminium reduction cell, creating fundamental conditions for stable and efficient operation of aluminium reduction cells at lower cell voltage [3].

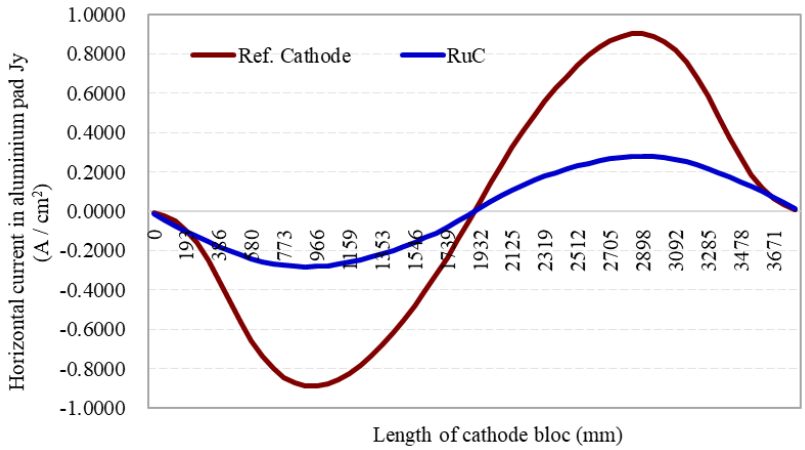

Figure 2. Comparison of simulated horizontal current distribution in aluminium pad [3].

Figure 3 shows the CVD trend of the 600 kA RuC cells compared to reference cells with steel collector bars over the past 54 months, the average CVD of the RuC cells is 162 mV, which is 48 mV lower than that of the conventional reference cells. The CVD of RuC cells is in relatively stable state for a long time, increases by an average of 4 mV per year, which is 5 mV lower than the increase in the reference cells. Projected over cell lifetime, assumed to be 2600 days, the average CVD is 167 mV.

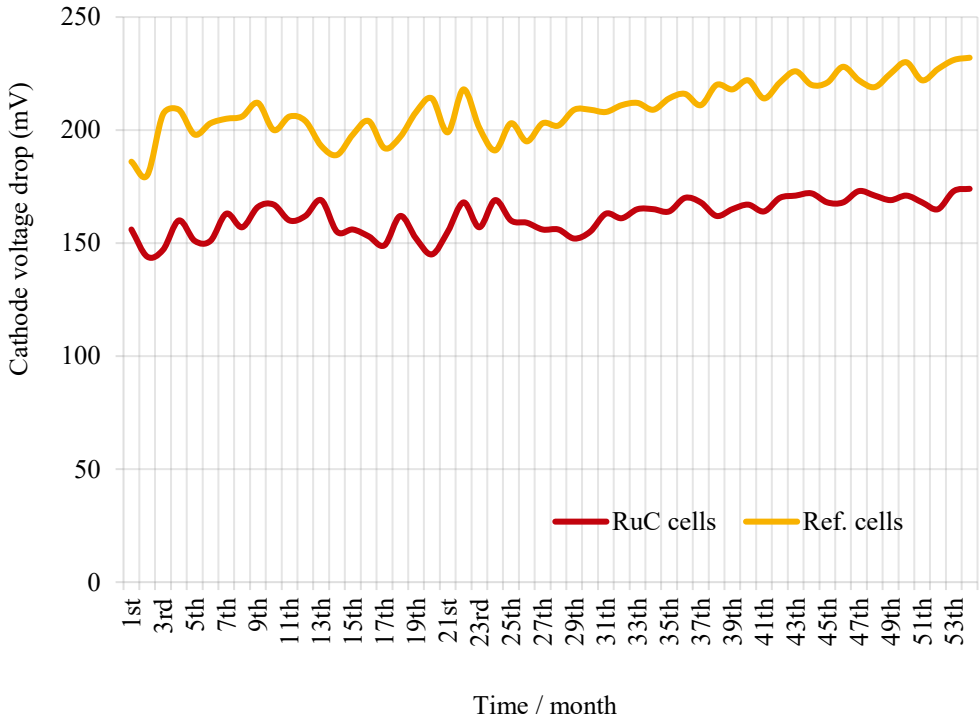

Figure 3. Comparison of CVD trend between 600kA RuC and reference cells.

In addition, actual measurements show that the 600 kA RuC cell maintains good uniformity of cathode current distribution; the current ratio between the upstream and downstream is generally around 51 % / 49 %. The uniform distribution of cathode current creates favourable conditions for the stable operation of the 600 kA RuC cells. Figure 4 shows measured cathode current distribution in a 600 kA RuC cell.

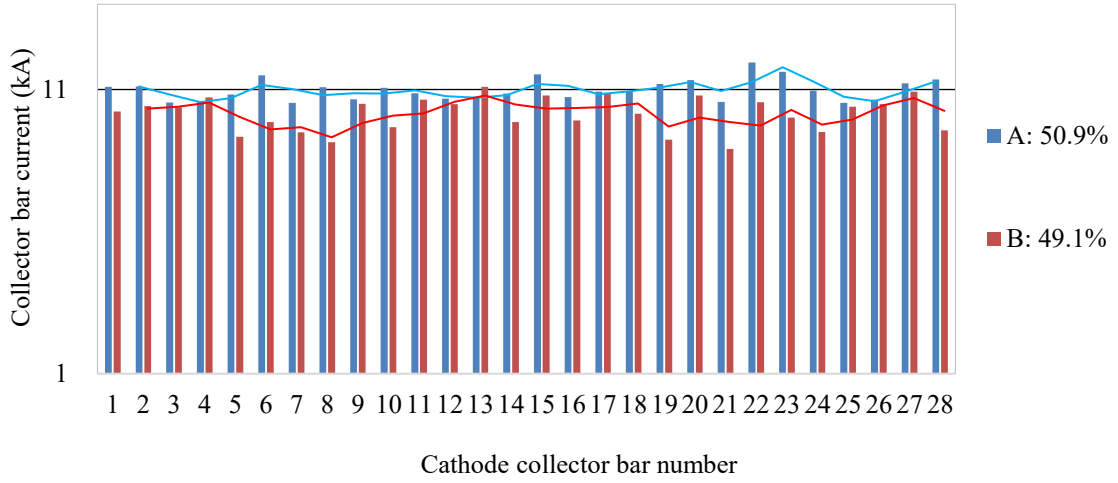

Figure 4. Measured cathode current distribution in 600 kA RuC cell.

3.2 An Important Contribution of RuC to Extending Pot Life

The RuC technology homogenizes the current distribution on the cathode working surface, significantly improving the uniformity of the current distribution within the cathode carbon block. According to the simulation results, the maximum current density of the cathode working surface has decreased by nearly 30 %. The uniformity of cathode current distribution was significantly improved, which is conducive to reducing the electro-chemical corrosion rate.

RuC uses full copper collector bars instead of steel collector bars, reducing the cross-sectional size of the conductive bars by about 80 %, which can significantly reduce the thermal stress and deformation of the conductive bar structure, thereby reducing the thermal stress and deformation of the cathode carbon block. The reduced metal volume in the collector bar is replaced by carbon cathode material which increases the distance from the collector bars to the cathode working surface [7].

Due to the structural advantages of RuC itself, under the same total height of carbon blocks, the effective carbon height and overall strength of cathode carbon blocks can be significantly improved, which is beneficial for improving the cell life.

Figure 5 shows the on-site cathode wear measurement for 600 kA reduction cells. Figure 6 shows the comparison of typical test results for cathode wear between 600 kA RuC and reference cells. After operating 4.5 years, the measurement shows that the maximum annual wear of 600 kA RuC cells is 25.5 mm, while the maximum annual wear of reference 600 kA cells is 34.8 mm. 600 kA RuC cells maximum annual wear is 9.3 mm smaller than the reference cells, a maximum wear rate reduction of 26.7 %. Based on the testing results, the service life of RuC cells is expected to be significantly extended.

Figure 5. Cathode wear test of 600 kA RuC and reference cells.

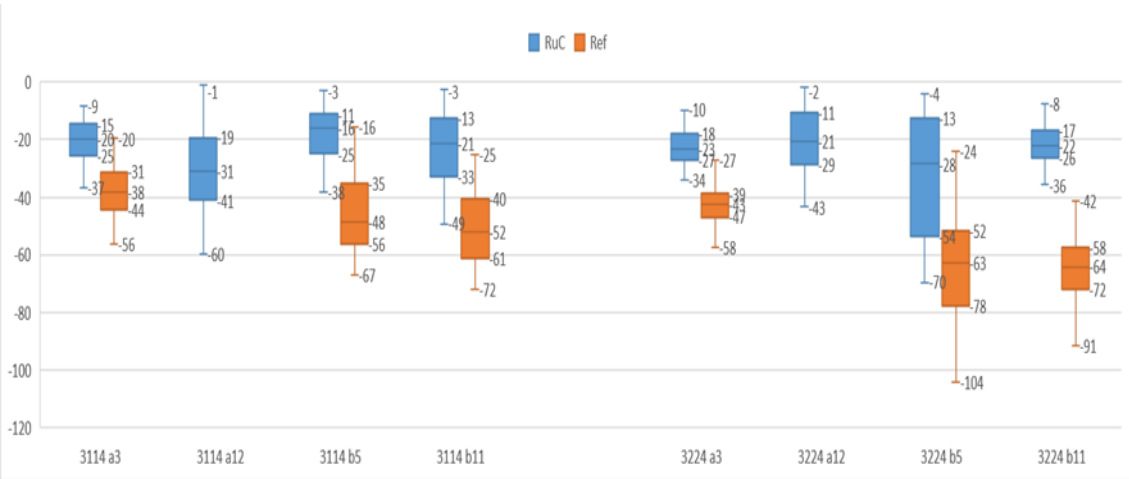

Figure 6. Comparison of typical measurement results for cathode wear between 600 kA RuC and reference cells.

3.3 Lining Configuration and Thermal Balance Design of RuC Cell

The lining configuration of the 600 kA RuC cell comprehensively enhances insulation performance of each area of the cell. The insulation space at the bottom and end of the cathode is improved, the insulation of the bottom and end areas of the cathode is increased, and an embedded insulation design on the Si_3N_4-SiC side blocks is used. Figure 7 shows simulation results temperature profiles in the 600 kA cell.

Through the optimization of lining configuration and thermal balance design, the RuC cells can maintain an ideal thermal balance at low voltage of 3.85–3.90 V, thus giving full play to the core technical advantages of RuC cell with high MHD stability and low CVD.

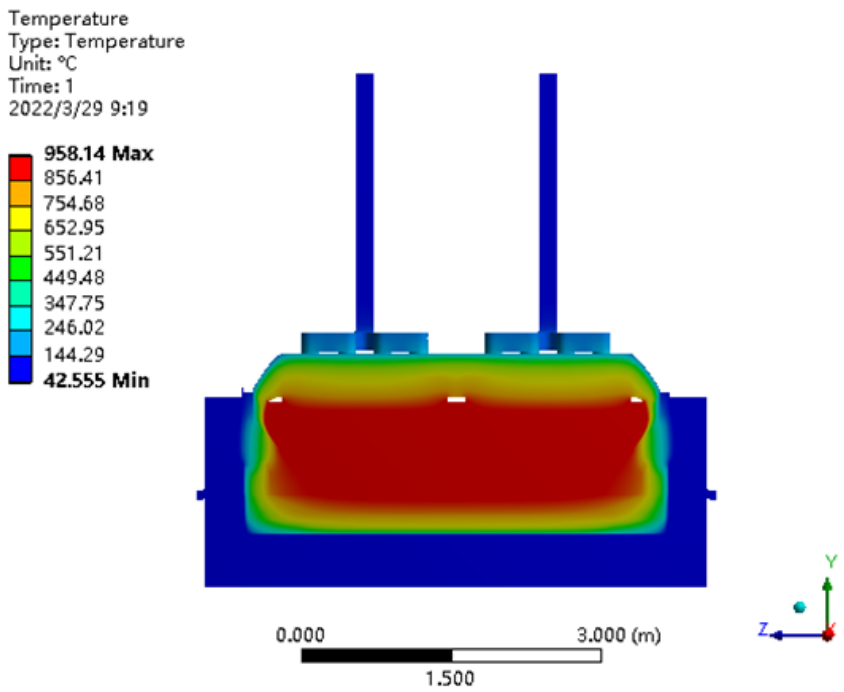

Figure 7. Simulated temperature distribution in 600 kA RuC cell.

3.4 Production Process Optimization Technology and Application Effects

In response to the technical characteristics of MHD stability, low CVD, and low heat loss of 600 kA RuC cells, the implementation of this project has formed a complete set of process technical specifications, including lining construction, preheating and start-up and production technical specifications.

As of the end of May 2025, two 600 kA RuC cells have been operating for more than 54 months and achieved excellent main technical and economic indicators. As shown in Figure 8, the operating voltage range of the RuC cells during the normal period is between 3.86–3.90 V, while the operating voltage range of the reference cells with steel collector bars is between 3.95–4.02 V. The average operating voltage of the RuC cells is about 100 mV lower than that of the reference cells.

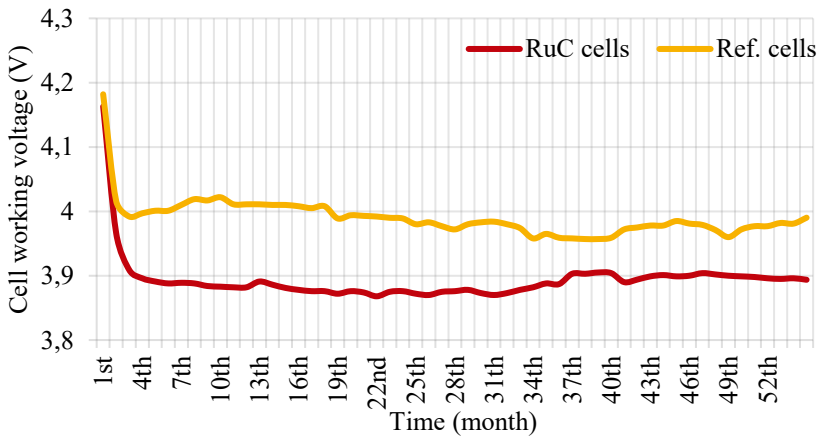

Figure 8. Comparison of working voltage between two 600 kA RuC and reference cells.

As shown in Figure 9, the average current efficiency of two 600 kA RuC cells during the normal period is 94.1 %, while the average current efficiency of the reference cells is 92.5 %. The current efficiency of RuC cells is 1.6 % higher than the reference cells.

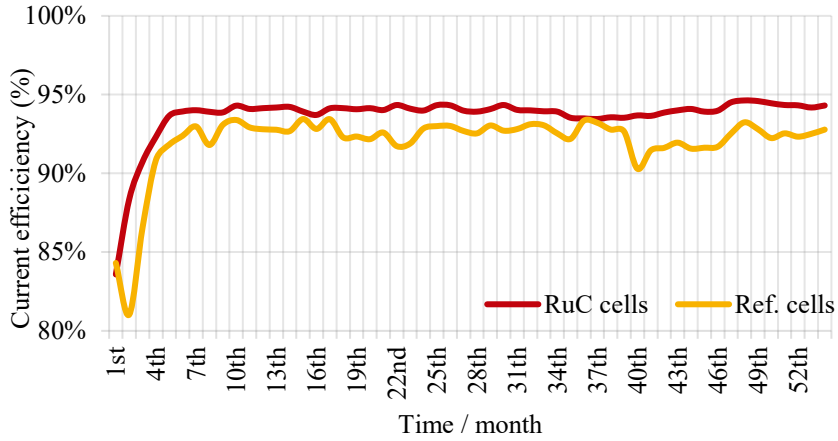

Figure 9. Comparison of current efficiency between 600 kA RuC and reference cells.

As shown in Figure 10, the average DC energy consumption of two 600 kA RuC cells during the normal period is 12 288 kWh/t Al, compared to 12 851 kWh/t Al in the reference cells. The average DC energy consumption of RuC cells is 563 kWh/t Al lower than that of the reference cells.

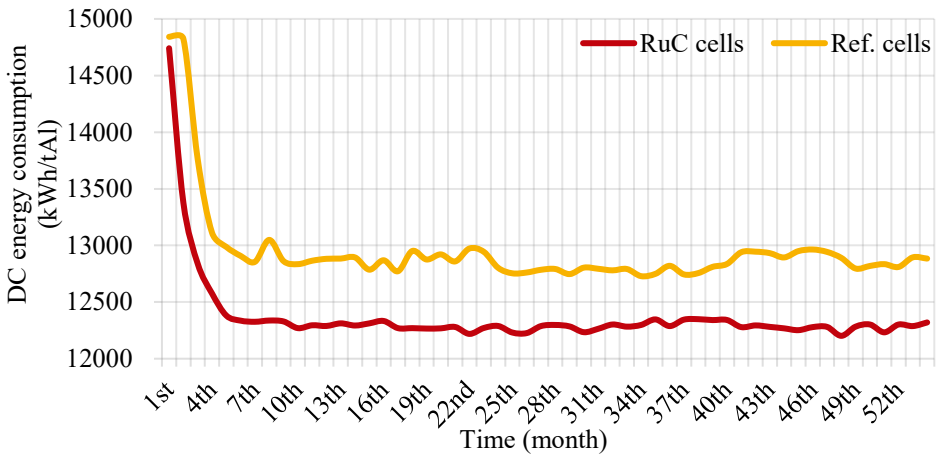

Figure 10. Comparison of DC energy consumption between two 600 kA RuC cells and reference cells.

4. Conclusions

The RuC technology has broken through the bottleneck of MHD stability core technology, enabling the reduction cells to operate stably and efficiently at lower cell voltages, achieving long-term stable energy saving, increasing current efficiency, and extending cell life of 600 kA cells. It is currently the most promising energy-saving technology in the industry, which can achieve significant energy-saving, carbon reduction, and extended cell life. RuC technology plays an important role in promoting technological progress and innovation in the industry, and more large-scale applications are underway in China [3].

5. References

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