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Stability Enhancement of DC Arcs in Reducing Argon-Hydrogen Atmospheres via Current Regulation

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Abstract

This work introduces an innovative method for controlling the stability of direct current (DC) arcs in reducing argon-hydrogen atmospheres, a key enabler for hydrogen-plasma smelting reduction (HPSR) processes aimed at decarbonizing steelmaking. By dynamically adjusting current, the system maintains robust arc behaviour under challenging conditions, supporting both process reliability and energy efficiency. The approach is based on modelling, integrating insights from detailed simulations and experimental data to optimize arc stability while minimizing hydrogen as well as energy losses and preventing unwanted arc extinction. Experimental validation is carried out on a laboratory-scale HPSR reactor equipped with advanced diagnostic instrumentation.

Power Supply

A high-frequency (50 kHz) pulse-width modulated (PWM) switching current regulator is employed to power the electric arc between a solid plate or melt bath and a hollow graphite electrode. A choke inductor smooths the current. Due to the high switching frequency, the required inductance is much smaller compared to the classical approach of using thyristor rectifiers. The concept is demonstrated at power levels up to 5 kW.

Operation

A mixture of argon-hydrogen gas is injected directly into the reactor through the electrode assembly. This configuration ensures precise control of the plasma environment and promotes efficient hydrogen utilization during iron oxide reduction. High-speed data acquisition systems capture voltage and current waveforms at microsecond resolution, enabling accurate characterization of transient arc phenomena. Synchronized video imaging provides visual insights, while additional sensors monitor temperature and other process variables. These measurements are used to validate simulation models and assess controller performance across a range of operating conditions, including variations in electrode distance, power input, and gas flow rates.

Outlook

The goal is to significantly enhance arc stability in argon-hydrogen atmospheres, reducing fluctuations and improving operational consistency. The integration of real-time measurements with predictive control enables adaptive optimization, ensuring efficient energy use and meeting hydrogen utilization targets. Future work will focus on transferring the system to an existing HPSR pilot plant, paving the way for advanced automation and digitalization in electric steelmaking. This development represents a critical step toward sustainable steel production, combining process innovation with environmental responsibility.

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