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SIMULATION-BASED ANALYSIS OF PRODUCTION FLEXIBILITY IN FOUNDRIES UNDER VOLATILE ELECTRICITY PRICES

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ABSTRACT

The energy transition is a challenge for energy-intensive industries such as non-ferrous foundries. It is important to support the transition to renewable energy sources through the electrification of melting plants. In particular, the fluctuating electricity supply and fluctuating electricity prices offer the opportunity to make melting plants more flexible and to keep energy-intensive processes low, especially when energy prices are high. This pilot study investigates how an electrified melting plant can adapt to the electricity market. For this purpose, a simulation model has been developed based on a selected example company. The energy consumption over time and the logistical effects of an operation are considered. The simulation model is implemented as a hybrid simulation combining a discrete event simulation at the plant level and a continuous process simulation within the furnaces. Simulation-based optimization can be used to determine an operational management strategy that is optimized in line with electricity prices.

1 INTRODUCTION

Climate change and the sharp rise in the cost of fossil fuels pose major challenges for energy-intensive industries. To counter this cost pressure, it is important to drive forward the switch to renewable energies in foundries. The integration of these sustainable technologies and into operational processes can be analyzed in advance with the help of simulations (Dettelbacher 2023). The electrification of melting units offers advantages in terms of process and material technology as well as the potential to replace fossil fuels, similar to electromobility. Another key advantage is the opportunity to benefit from lower electricity prices, particularly through flexible production. Keeping the molten aluminum material warm serves as a production buffer and allows flexibility with regard to the melting time of new material. In addition, the material demand can be made more flexible by adjusting the sequence of the casting components.

As part of this pilot study, electrified operation will be modeled in a simulation model using a selected foundry. Different model levels are used to describe the material and energy flow both at production level and in the melting units. The model is then used as part of a simulation-based optimization to plan production for day-ahead electricity trading in Germany. The aim is to investigate flexibility options and quantify the impact on production and energy costs.

2 MODELING

A special aspect of modeling a melting and casting process is that the process includes both discrete-event and continuous processes. While the material flow contains both discrete (e.g. forklift transport) and continuous (e.g. melting process) components, the energy flow is modeled purely continuously. Therefore, a hybrid simulation model is applied, which combines a discrete-event and continuous simulation. At the factory level, the material flow is simulated discretely by events, while the melting furnaces are represented by a finite state machine for the machine states and a continuous process simulation for the internal material and energy flow. The heating, melting and overheating processes are physically modeled, with the state variables mass and energy modeled as stocks and flows. The continuous material flow during the melting process is solved using ordinary differential equations, which consider the interaction between material and energy flow in a bidirectional way. The simulation levels are coupled with each other so that both the entities from the discrete-event simulation influence the continuous state variables with their attributes and continuous signals also trigger events at a threshold value. Setup processes and machine breakdowns can be mapped in the state machine.

The Matlab environment Simulink is used for the implementation. The SimEvents toolbox is used for the discrete event elements and the machine states are modeled using the Discrete Event Chart. The model is used as part of a simulation-based optimization, as shown in the schematic illustration in Figure 1. Energy costs are reduced as an objective function, while production-related constraints ensure undisturbed production. By adjusting the production plan and shifting the melting times, electricity consumption is shifted and energy costs are minimized.

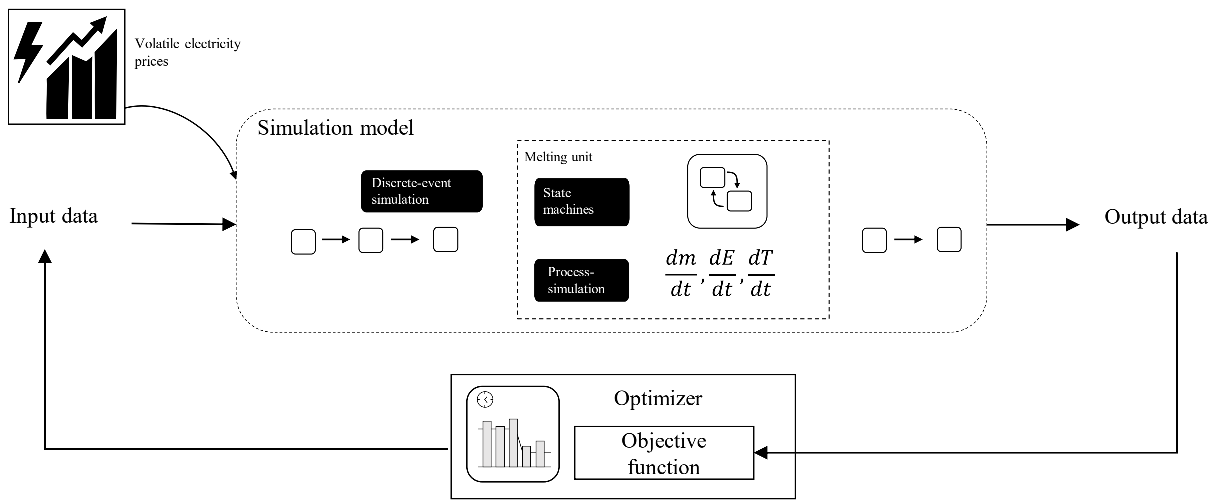

Figure 1: Simulation-based concept for the energy flexibilization of melting plants

3 SIMULATION STUDY

As part of a simulation study, the possibilities for increasing the flexibility of an electrified melting and casting operation were determined. For this purpose, an operation with 24 die casting machines was considered. The flexibilization options considered were an adjustment of the production schedule and a shift of the melting time. As evaluation criteria, the energy costs are determined via the energy consumption and the electricity prices over time. Production logistics and energy-related contraints are defined. As part of the simulation-based optimization, the production plan is used as input data for the simulation. For this purpose, the production plan is first decoded into integer variables. The plan is then used by simulation and adjusted by the optimization algorithm on the basis of the output data and the specified objective function.. The genetic algorithm is used as the optimization algorithm and the implementation is carried out using the Global Optimization Toolbox in Matlab. The model was tested with historical electricity prices in Germany and can also be used for real day-ahead electricity prices in the future. Some test data has shown that considerable savings in energy costs are possible without affecting production. The savings will continue to increase due to the expansion of renewable energies and the increasing volatility of electricity prices.

REFERENCES

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