Increasing the flexibility of a fixed-bed biomass gasifier through model-based control strategies

Method and practical verification

Clemens Hollenstein, Christopher Zemann, Stefan Martini, Markus Gölles, Wolfgang Felsberger, Martin Horn

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Motivation

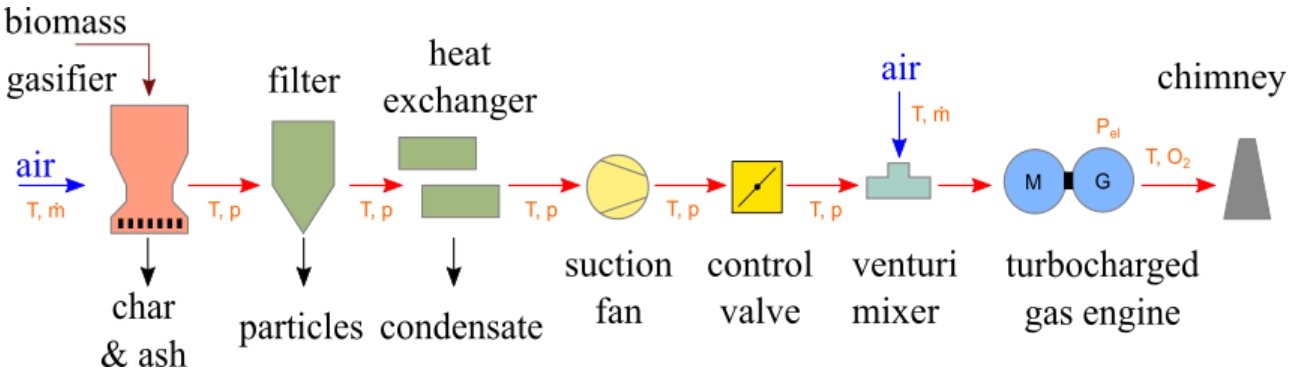
Future hybrid energy systems require flexible technologies for compensating volatile fluctuations

- Fixed-bed biomass gasification systems principally allow flexible operation but
  - their control strategies are typically optimized for nominal load
  - partial load operation typically needs manual interventions of the plant operators to keep efficiencies high and to counteract operational difficulties

Advanced control strategies are required to unleash the full potential and allow a fully-automatic, flexible operation in the future

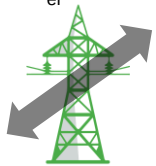
Development of an advanced control strategy

On the basis of a representative, industrial plant



feedstock variations

load modulations
(100kW$_{el}$ to 150kW$_{el}$)



Process analysis reveals two key challenges in operating strategy:

- Char handling during partial-load operation
- Consideration of process parameters coupling

Requirements of the new control strategy

Improve char handling and decoupling of process parameters

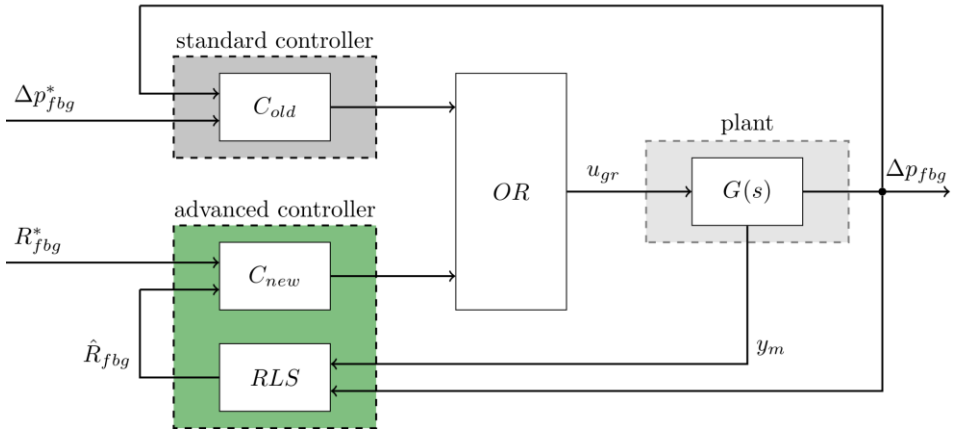
- Char handling in reduction zone → new grate controller
  - stabilization of char bed inside the fixed-bed gasifier
  - load-independent control of the rotatable grate

- Decoupling of process parameters → new decoupling controller
  - decoupling of electric power and gas pressure for load modulations
  - simultaneous control of suction fan and control valve

Model-based control design increases reusability and
allows explicit consideration of interrelations and disturbances

Grate controller

The pressure-based *standard control* is load-dependent



- Mass flow of gas passing through gasifier affects its pressure drop
- Flow resistance is a proper load-independent process parameter

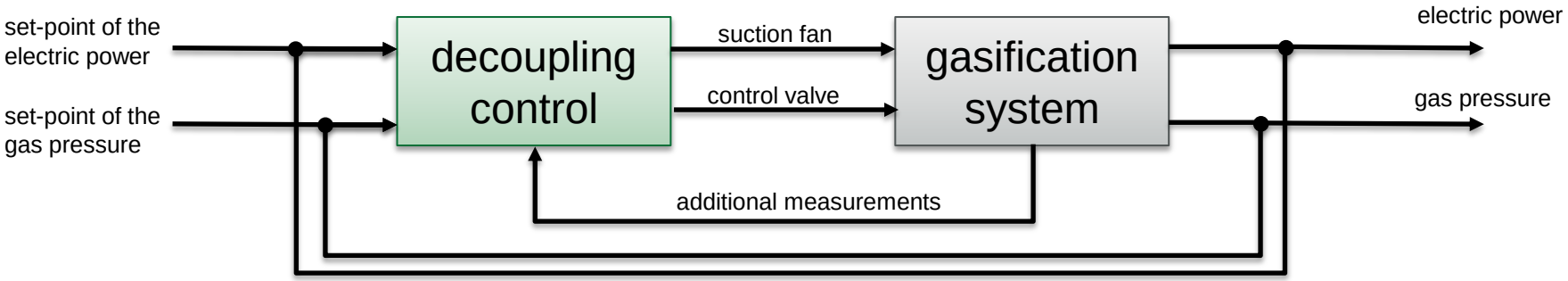
$$\underbrace{\Delta p_{fbg}}_{\text{Pressure drop}} = \underbrace{{\nu_{rg}}^{0.25}\ {\rho_{rg}}^{0.75}\left(k_{rg2ga}\ \frac{\dot{V}_{ga}\ \rho_{ga}}{\rho_{rg}}\right)^{1.75}}_{\text{modelled function}}\ \underbrace{R_{fbg}}_{\text{flow resistance}}$$

Change from pressure-based to flow resistance-based control to maintain suitable amounts of hot char inside

Model parameter: kinematic viscosity ν_{rg}, gas density ρ_{rg}, volume flow rate of air $\dot{V}_{ga}$, density of air ρ_{ga}, tuning factor k_{rg2ga}

Decoupling controller

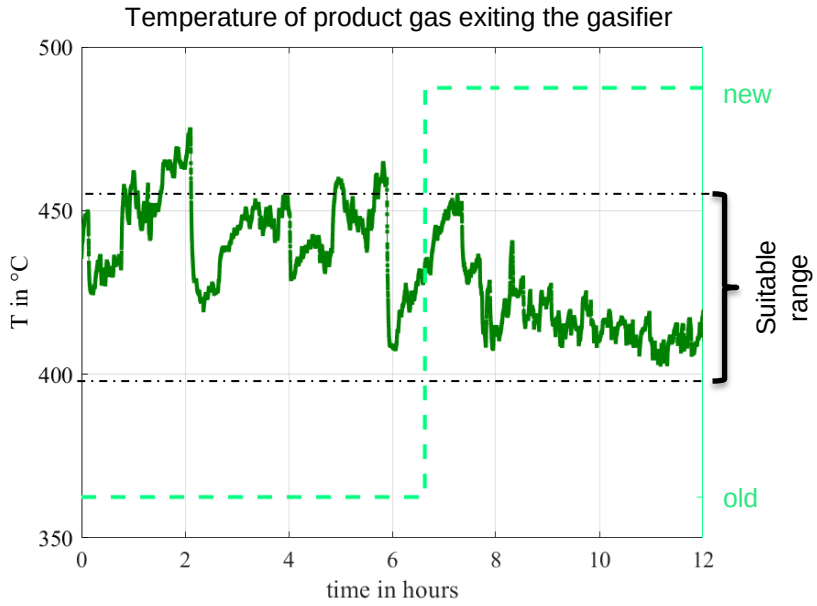
A multivariable and model-based control approach is required

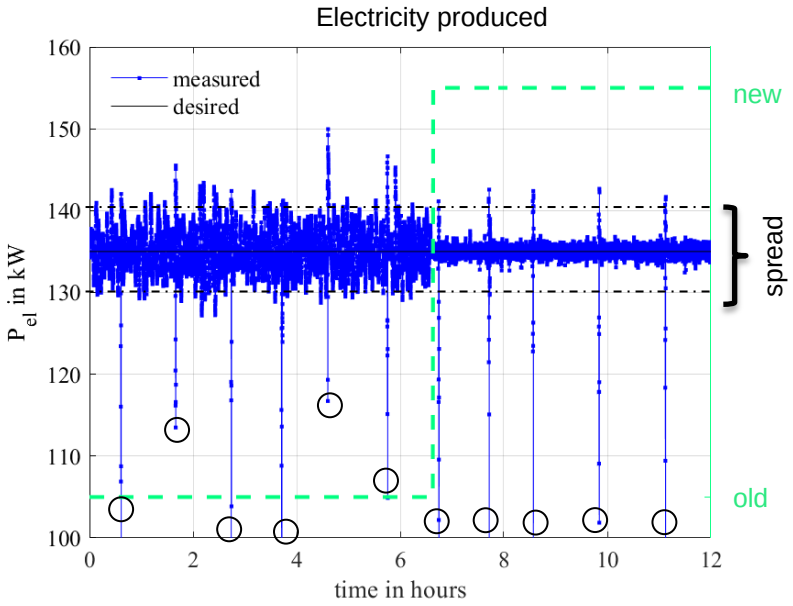


Simultaneous manipulation of the suction fan and control valve for a decoupled electric power and pressure control

Validation at steady-state

Exemplary practical verification at partial-load operation



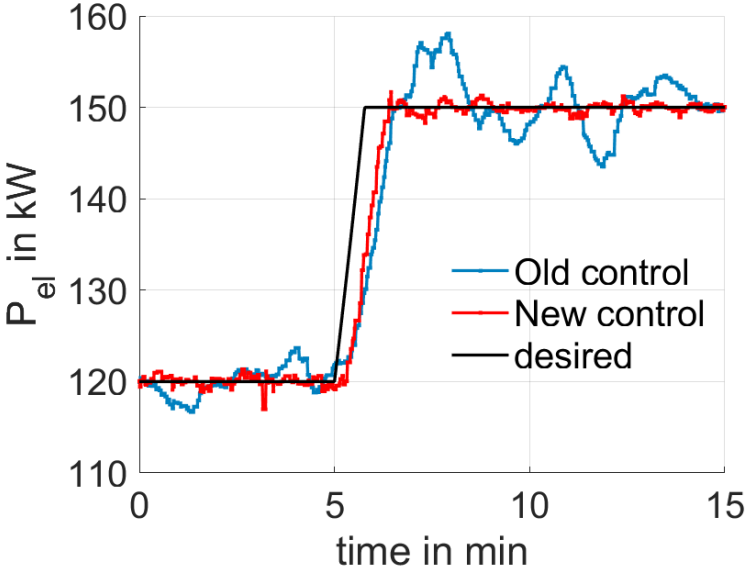


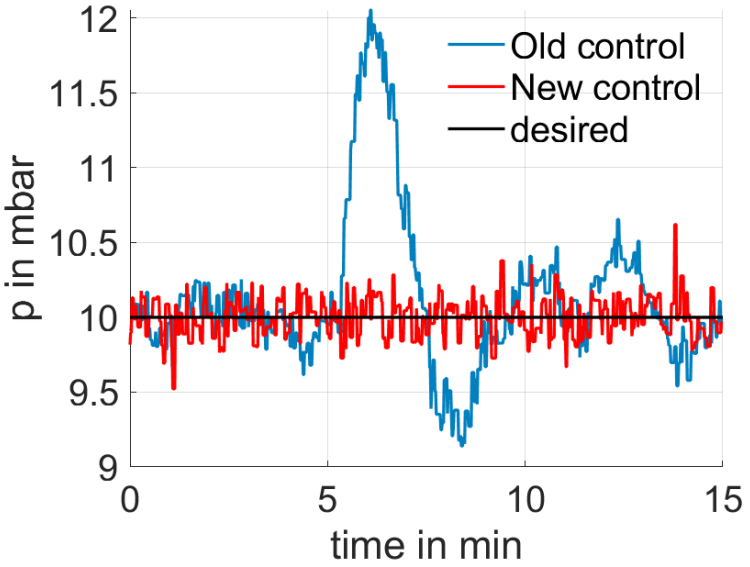
- Gas temperature stabilizes in a suitable range
- Spread of electric power is significantly reduced by the new controller

○ …periodical hot gas filter cleaning

Validation of load modulation capability

Exemplary practical verification during a load increase

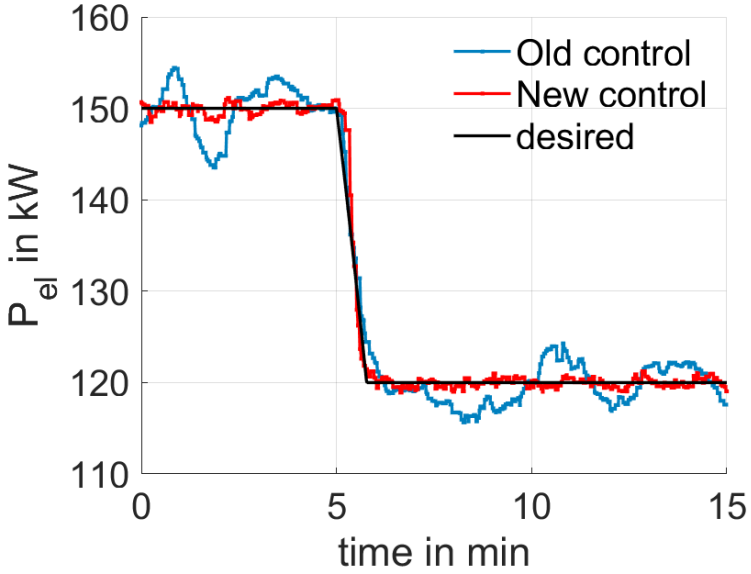


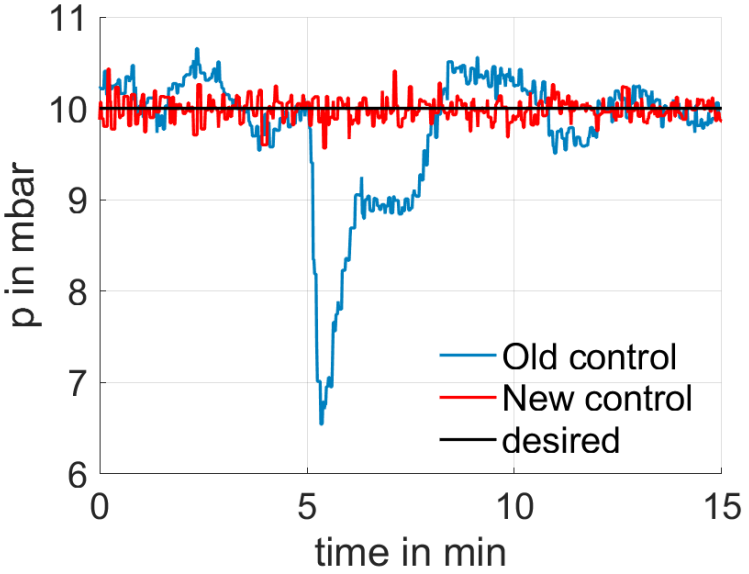


- New control increases electric power faster (settling time)
- Compensates mutual effects on the pressure and fluctuates less

Validation of load modulation capability

Exemplary practical verification during a load decrease





- New control decreases electric power as fast but with less fluctuations
- Maintains gas pressure more precisely at its desired set-point

Conclusion and outlook

- Designed, implemented and practically verified model-based controllers
  - load modulation capability is significantly increased
  - actual gasification process is more homogeneous at varying loads

- Reasonable next steps
  - demonstration and validation at different plants
  - development of an efficient method for the model- and control parameter adaptation

Model-based control strategies can increase the operational flexibility of fixed-bed biomass gasification systems

TRL5 … technology readiness level 5 – “technology validated in relevant environment” [Horizon2020]

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Dipl.Ing. Clemens Hollenstein
Bioenergy and Sustainable Technologies GmbH
Researcher in Automation and Control
+43 5 02378 9222
clemens.hollenstein@best-research.eu

FFG Forschung wirkt.
Bundesministerium Arbeit und Wirtschaft
Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie
wirtschaftsagentur wien
Für die Stadt Wien
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