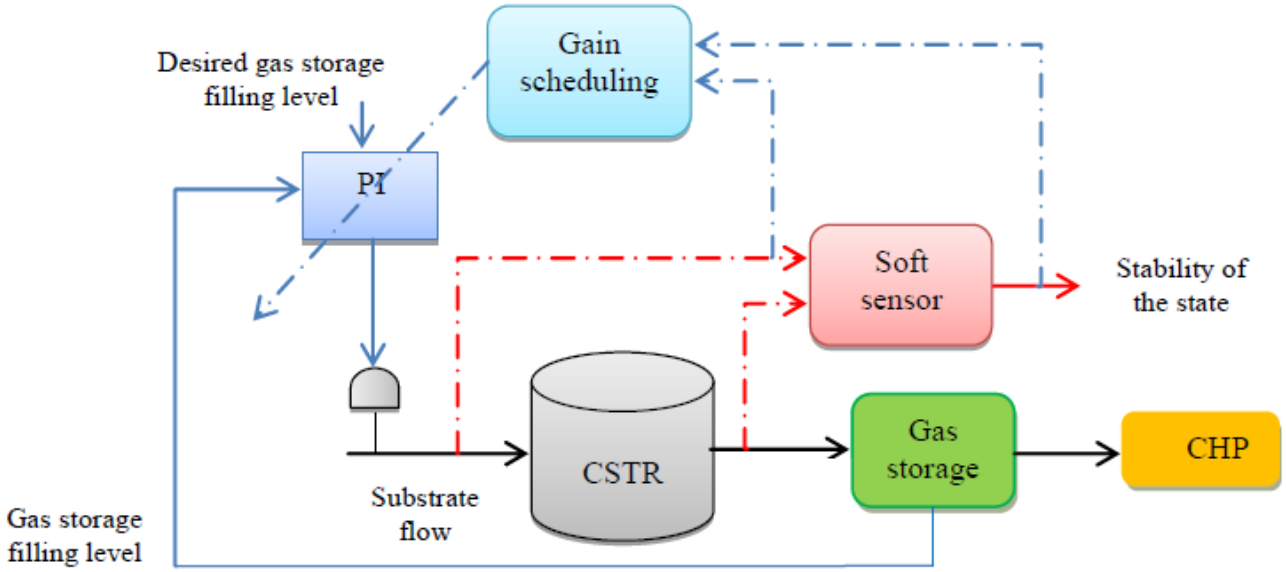


Flexible methane production using PI controller with simulation based soft sensor

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Christian Wolf

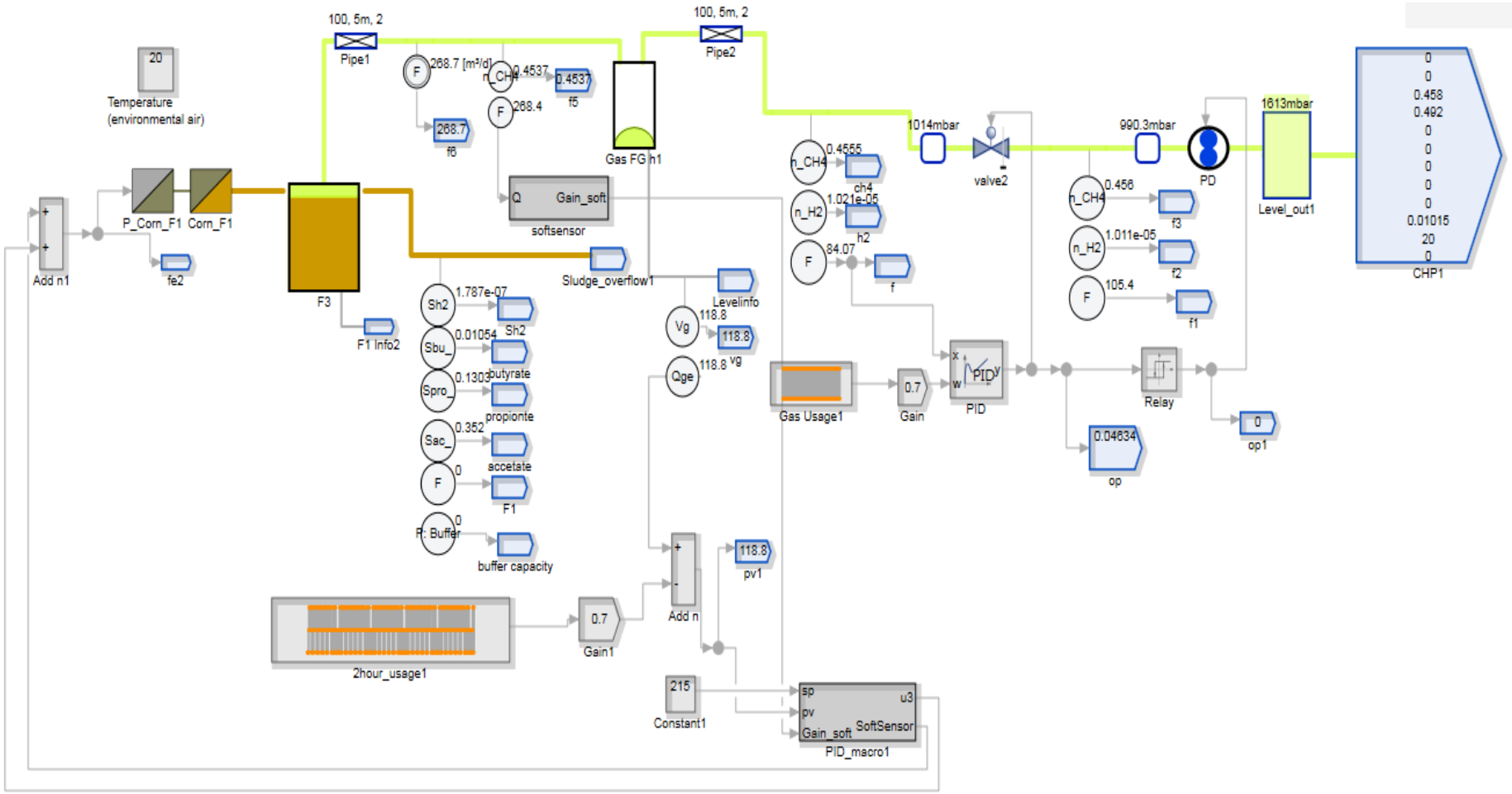
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Overview

- Introduction
- Calibration
- Usage scenario and Plant parameters
- PI Controller tuning
- Digitalization of the controller & Tracking anti wind-up
- Influence of Gain scheduling and anti wind up on controller
- Soft sensor development
- Secondary Gain scheduling based on soft sensor
- Influence of second gain scheduling
- Comparing results with constant biogas production
- Conclusion

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Introduction



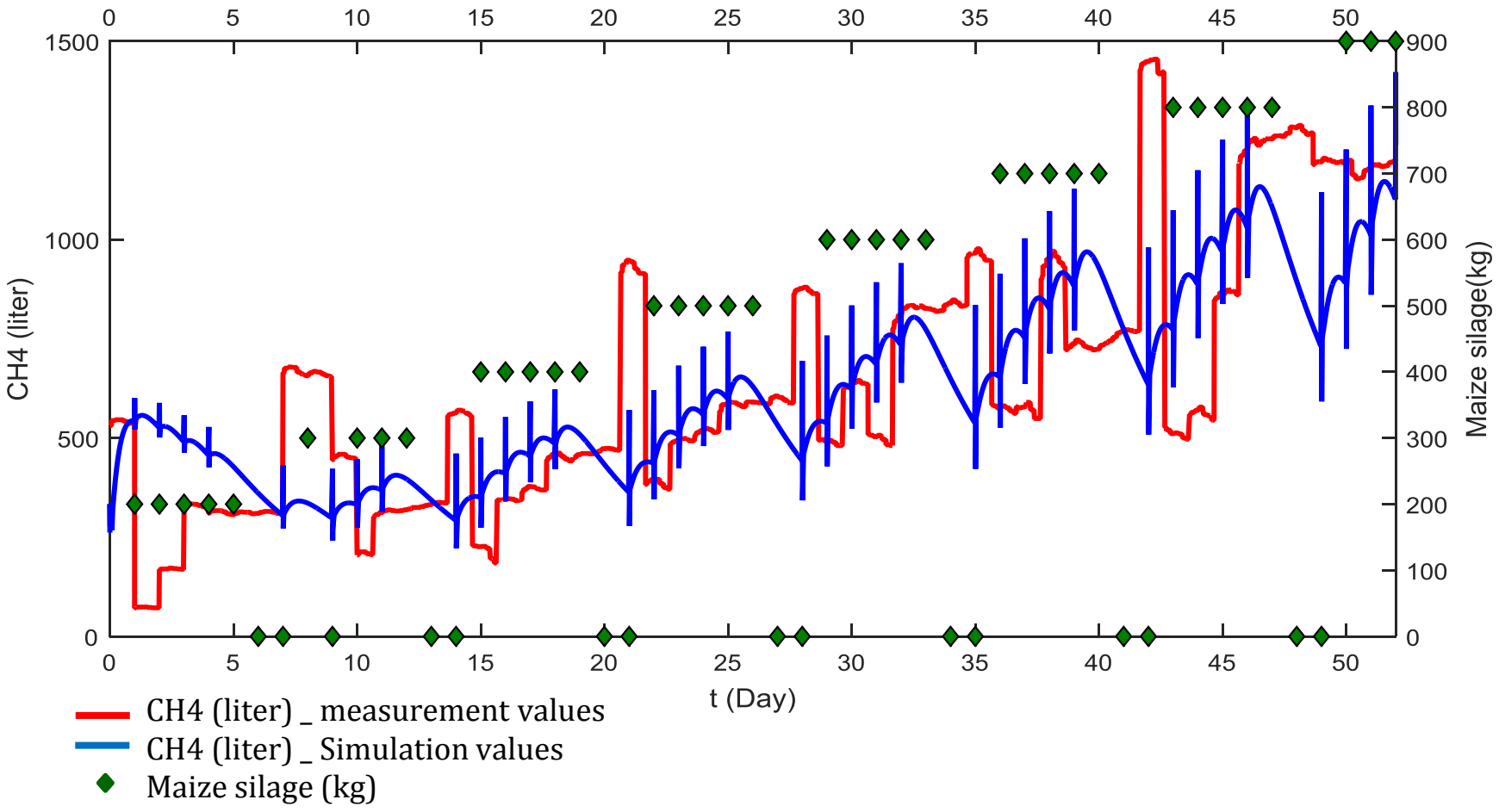
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Calibration

Mini biogas plant Metabolon _ Experimental setup						
Reactor volume				$2 * 100\ m^3$		
Operating temperature				40 °C		
Organic loading rate				$2 * 100\ kg/day$		
Feed composition	TSS $(\frac{kg}{t})$	VSS $(\frac{kg}{t})$	Crude protein $(\frac{kg}{kg})$	Crude lipid $(\frac{kg}{kg})$	Crude fiber $(\frac{kg}{kg})$	Ammonia nitrogen $(\frac{kg}{t})$
Maize silage	500	485	0.0869	0.0368	0.177	0.66

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Calibration-results



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Usage scenario and Plant parameters

[4]	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Utilization times	7 – 15	7 – 14	7 – 15	7 – 14	7 – 14	9 – 12	0 – 1
	16 – 22	15 – 22	16 – 22	15 – 22	16 – 23	17 – 23	11 – 12
							17 – 0

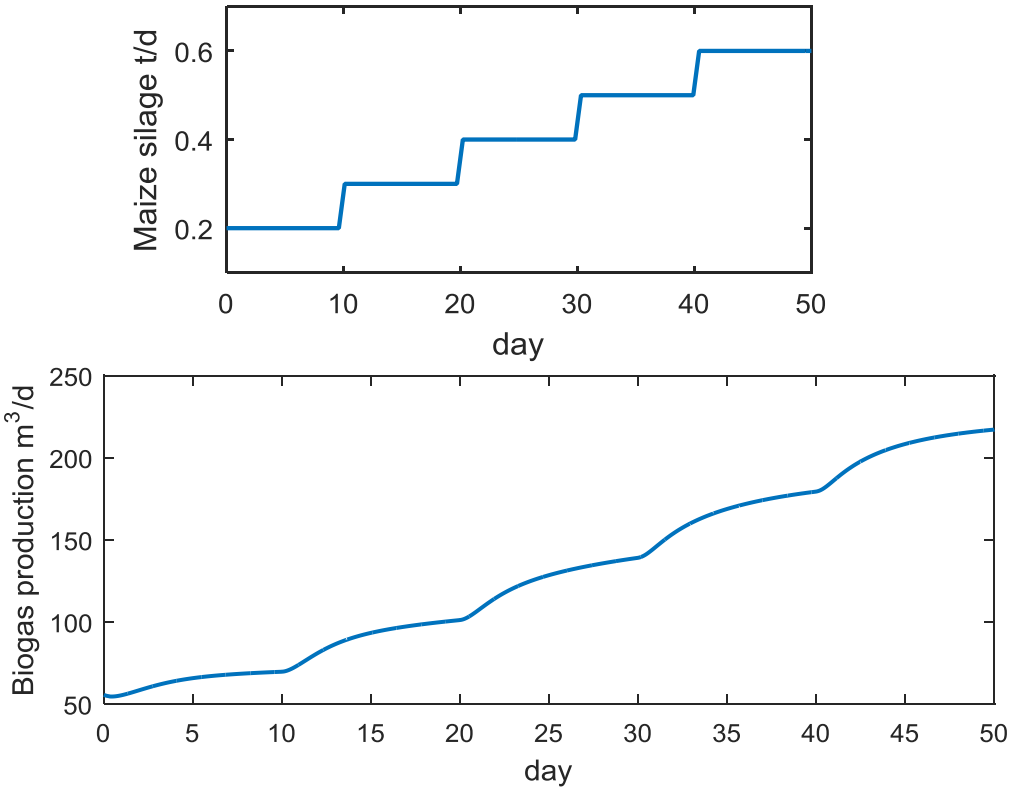
Usage amount per hour = 1.6*average gas production = 14.9 $[m^3/h]$

Parameters	Values
Storage capacity volume	500 $[m^3]$
Initial gas volume in storage tank	300 $[m^3]$
Maximal feeding amount	6 $[td^{-1}]$
Maximal feeding velocity	8 $[th^{-1}]$
Substrate feed	Maize silage

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PI Controller tuning

A. Estimating transfer function from step response for different operating points:

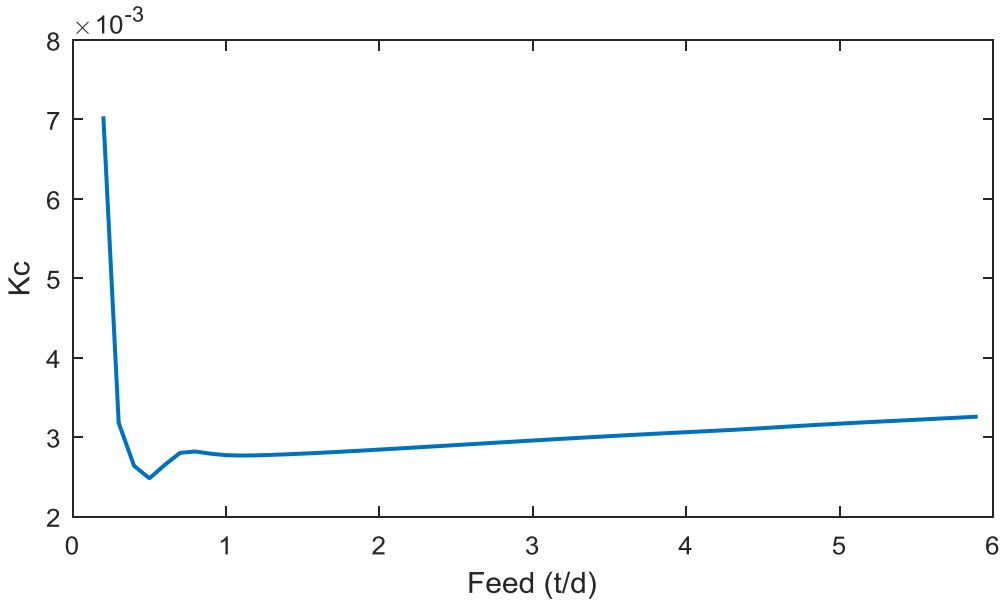


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PI Controller tuning _Gain Scheduling

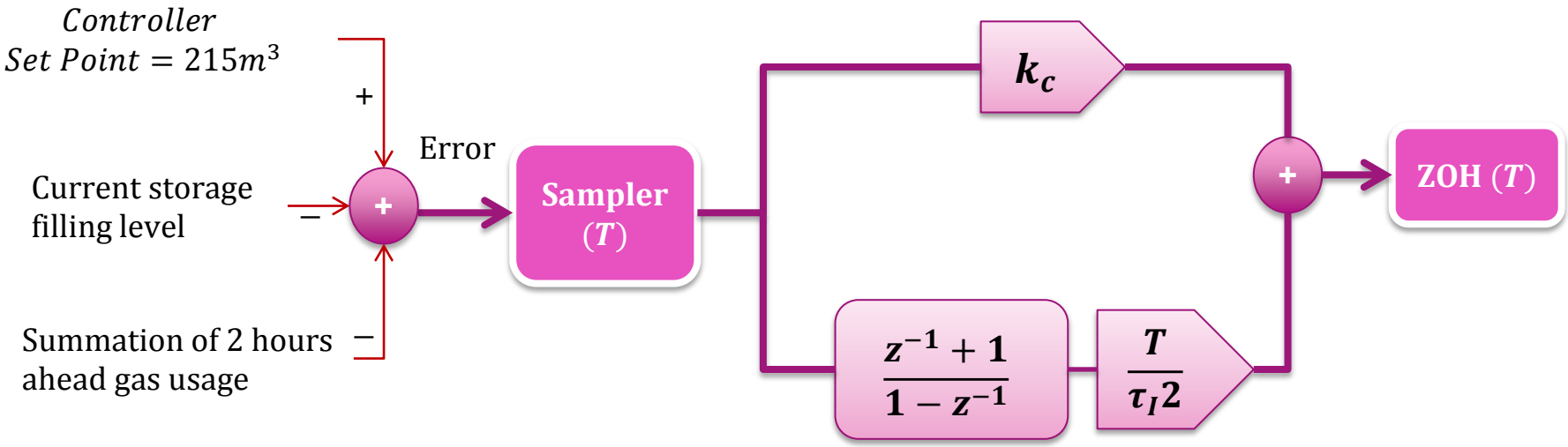
B. IMC-Based PI Design for a First-Order Process:

$$PI = K_c + \frac{1}{\tau_I s}, \qquad G_p = \frac{k_p}{\tau_p s + 1}, \qquad K_c = \frac{\tau_p}{k_p \lambda}, \qquad \tau_I = \tau_P$$



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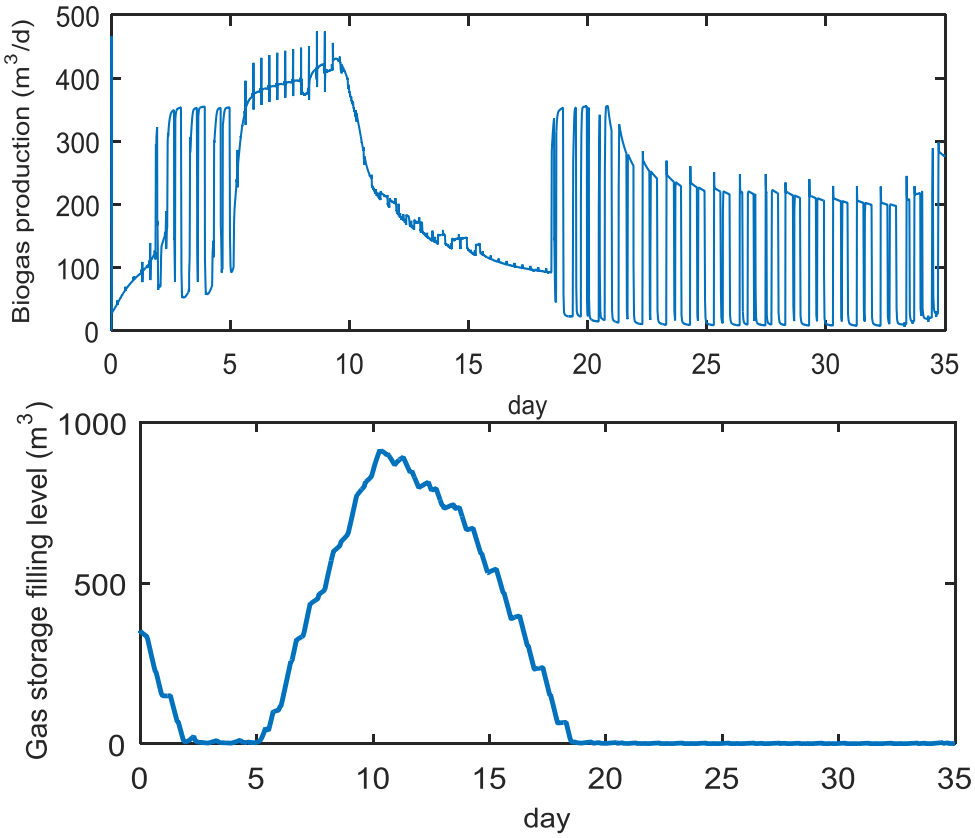
Digitalization of the controller

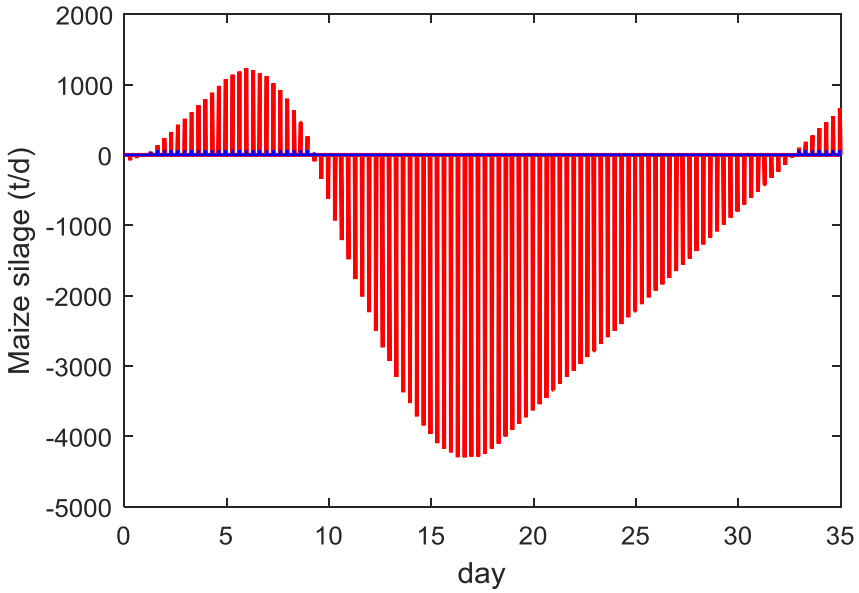


Sampling time (T) = 8 hours

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Simulation results – Without Gain scheduling and without anti wind-up

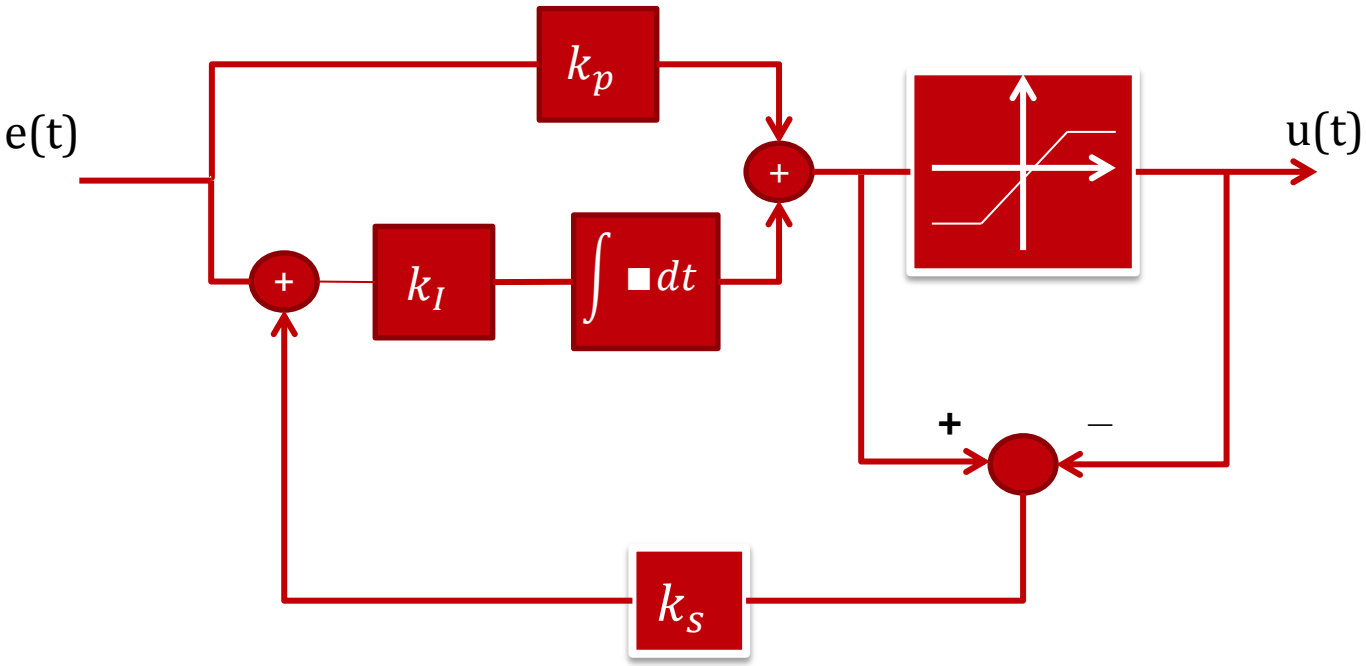




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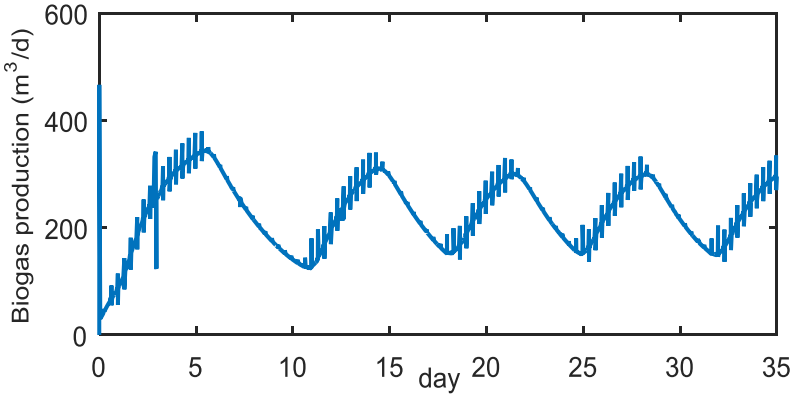
Tracking anti wind-up

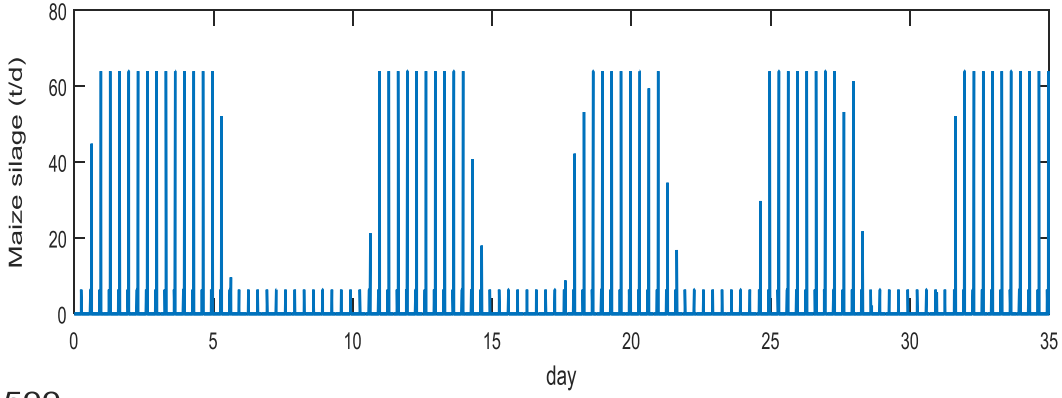


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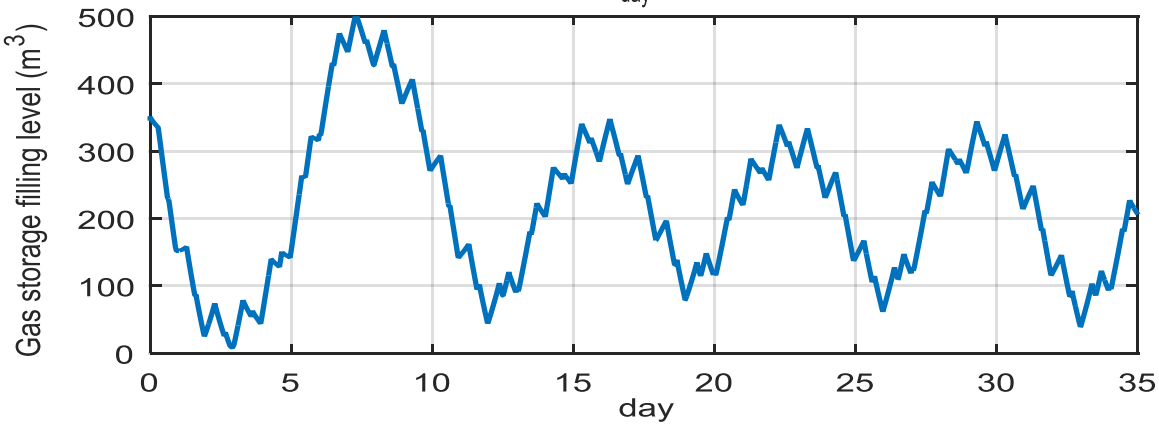
Simulation results – With Gain scheduling and anti wind-up





After start up:

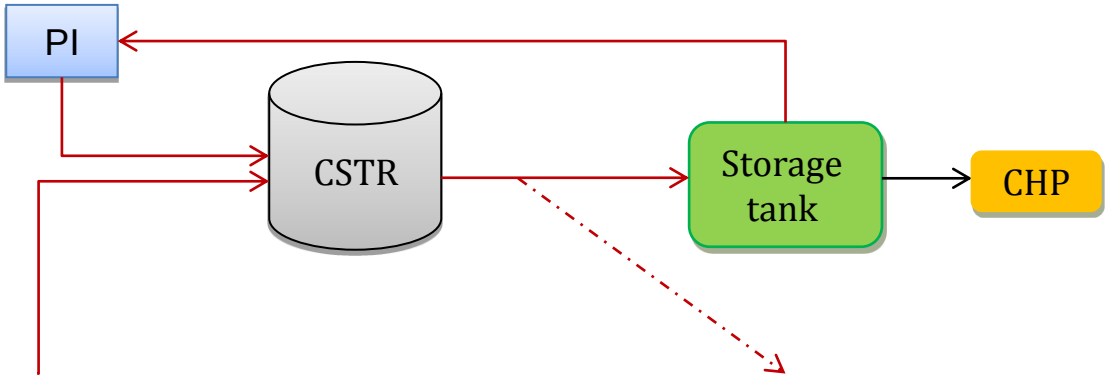
- Storage level can be kept between: 39 m^3 *and* 325 m^3

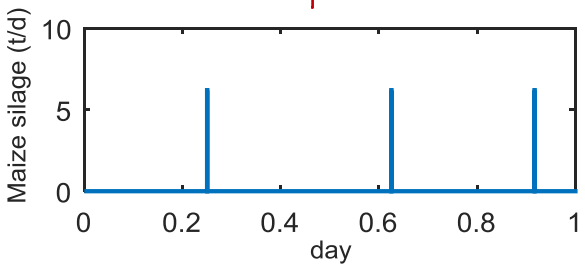


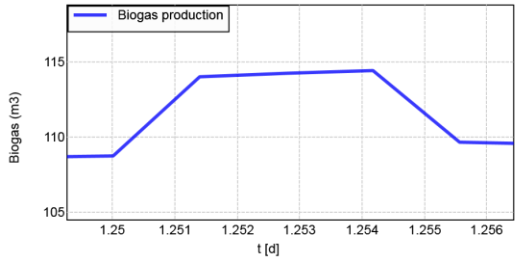
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Soft sensor development



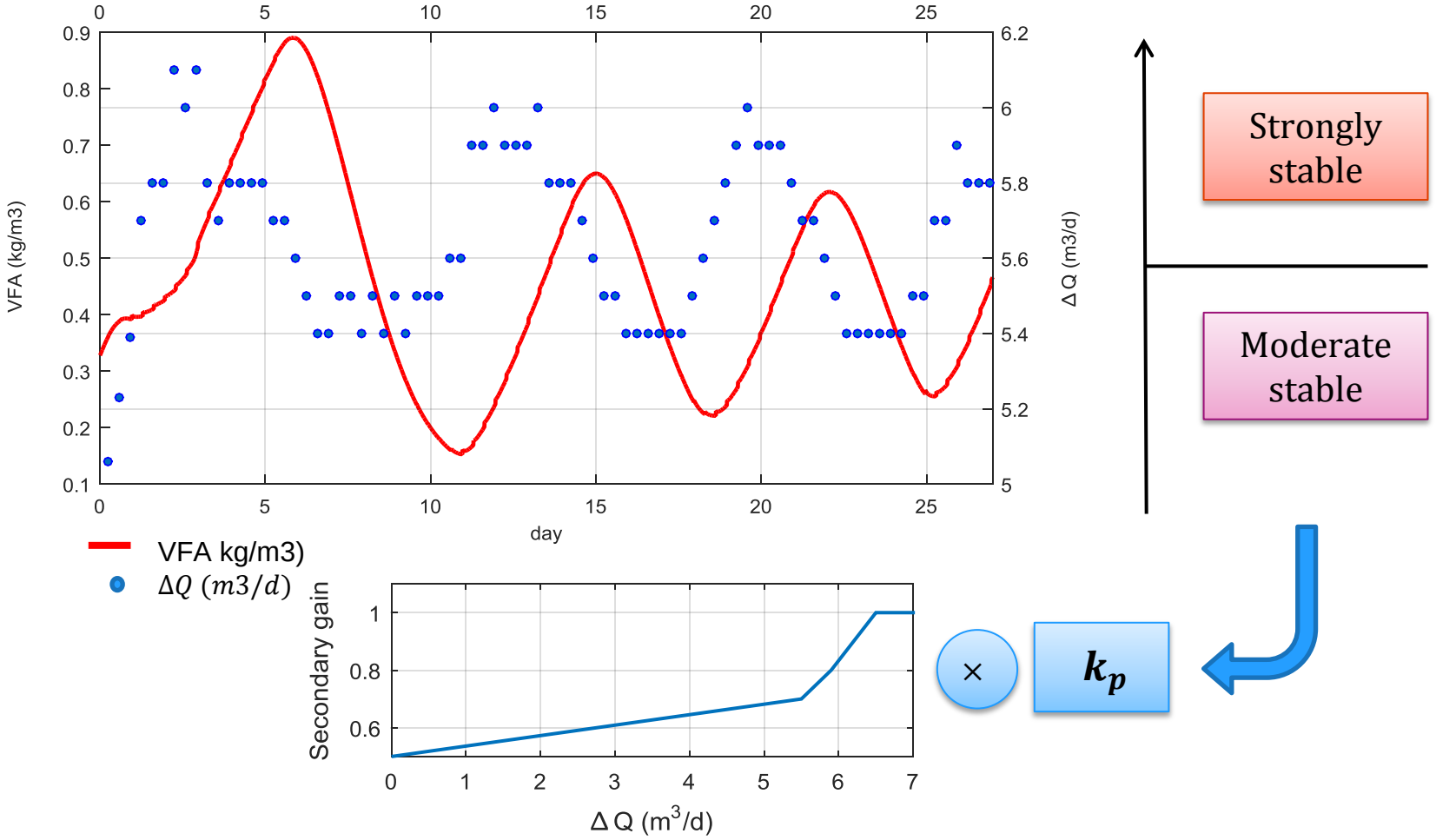




ΔQ will be calculated after applying each pulse

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Soft sensor _Secondary Gain scheduling



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Influence of second gain scheduling

1. Less variation over the storage filling level set point value with soft sensor
2. After the start-up interval, less variation over VFA with soft sensor

Without soft sensor	Week 1	Week 2	Week 3	Week 4	Week 5
215 (m^3)– minimum filling level	206.59 (m^3)	170.82 (m^3)	136.05 (m^3)	153.37 (m^3)	175.8 (m^3)
Maximum filling level – 215 m^3	-	299.7 (m^3)	132.7 (m^3)	124.3 (m^3)	129.2 (m^3)
Maximum VFA	0.89	-	0.63	0.62	0.7
Minimum VFA	-	0.15	0.22	0.25	0.29

With soft sensor	Week 1	Week 2	Week 3	Week 4	Week 5
215 (m^3)– minimum filling level	206.08 (m^3)	170.22 (m^3)	94.7 (m^3)	122.76 (m^3)	149.57 (m^3)
Maximum filling level – 215 (m^3)	-	299.7 (m^3)	136.1 (m^3)	103.2 (m^3)	114.1 (m^3)
Maximum VFA	0.89	-	0.67	0.59	0.64
Minimum VFA	-	0.14	0.22	0.28	0.32

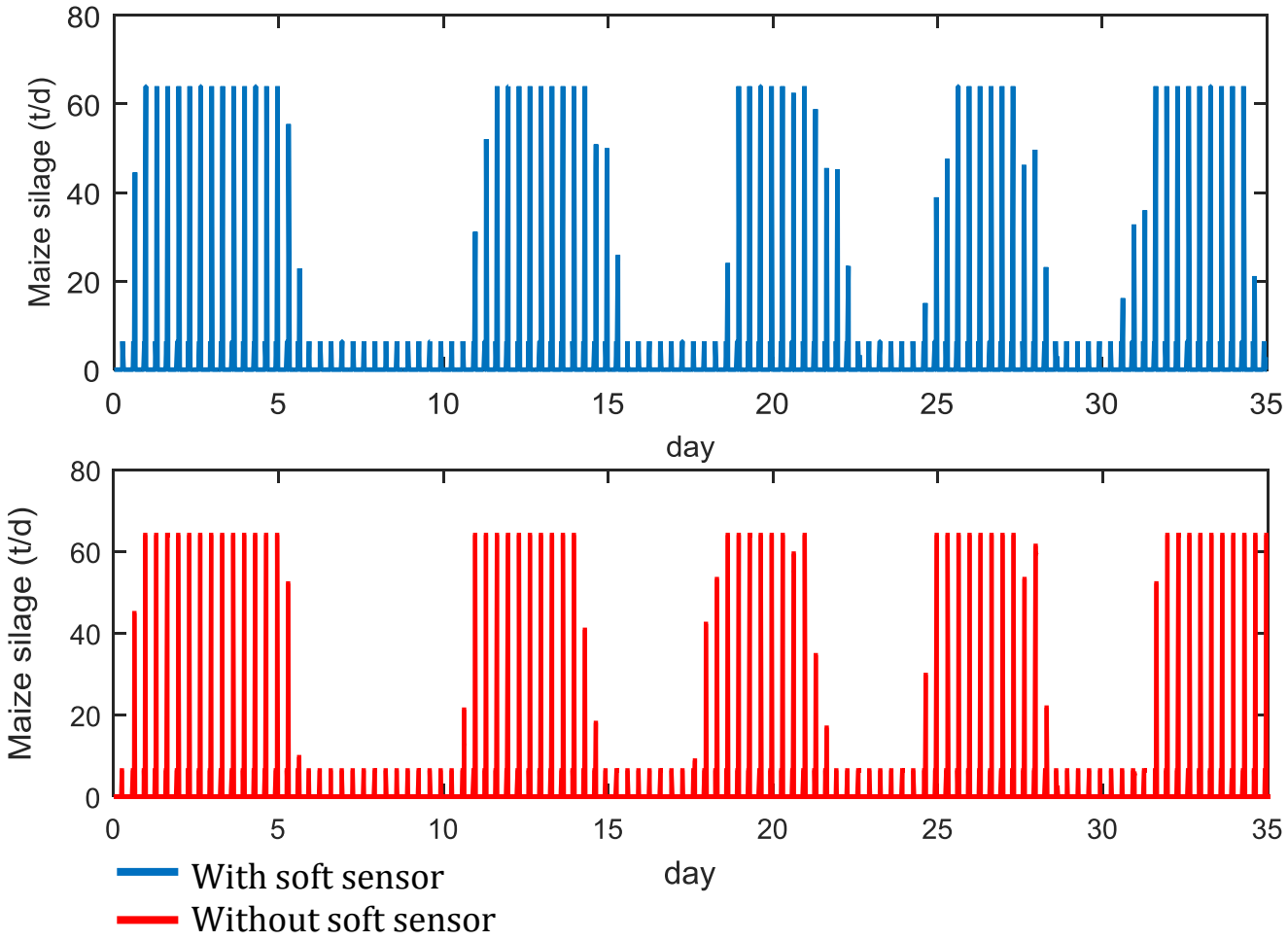
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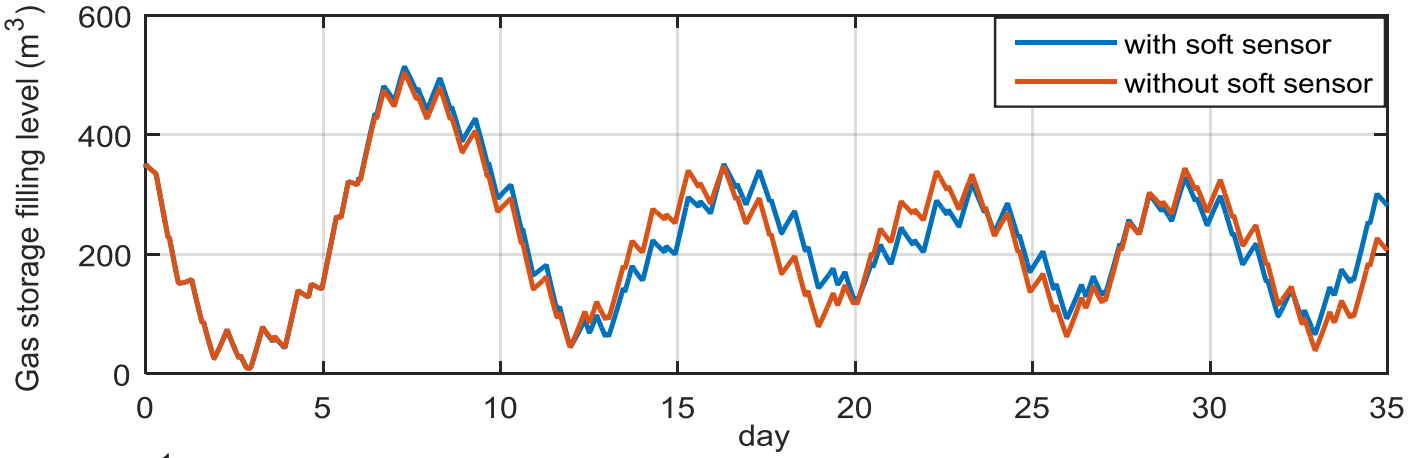
3. Smaller average Maize silage usage with soft sensor

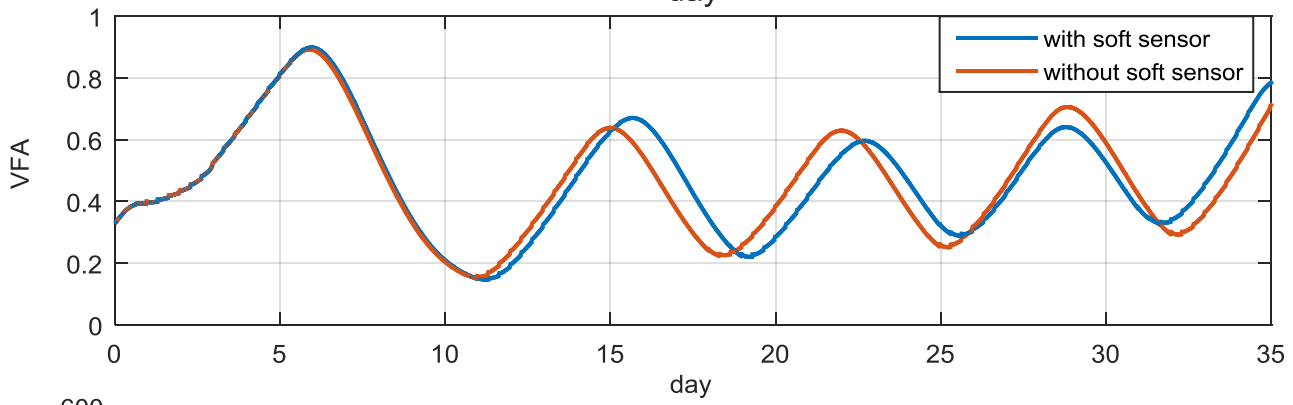
Average feed = 0.66 (t/d)

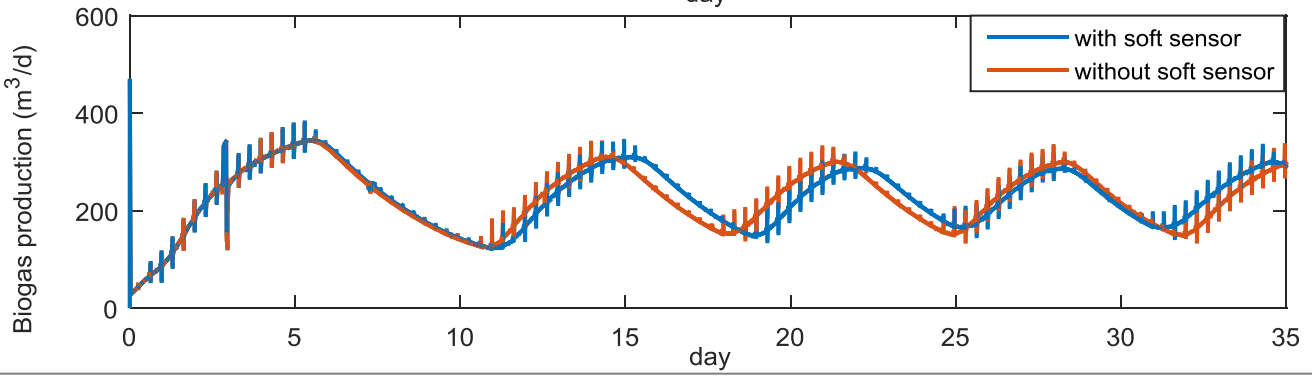
Average feed = 0.67 (t/d)



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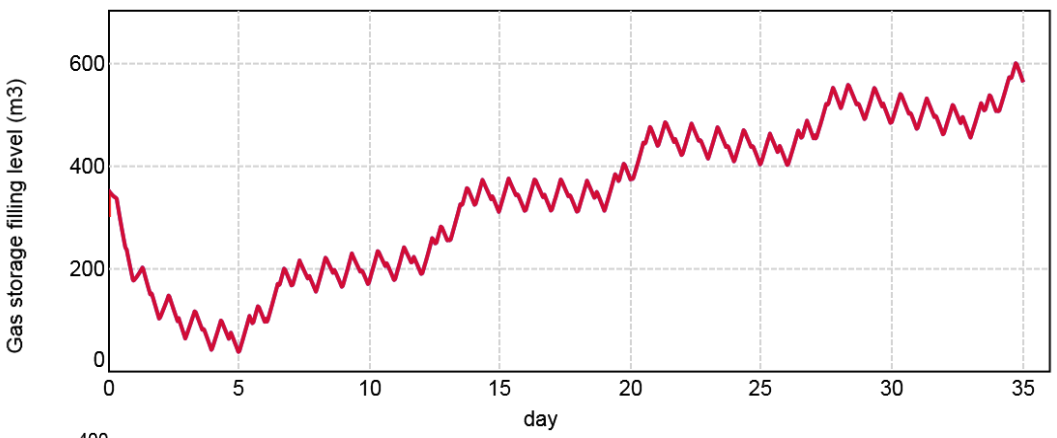


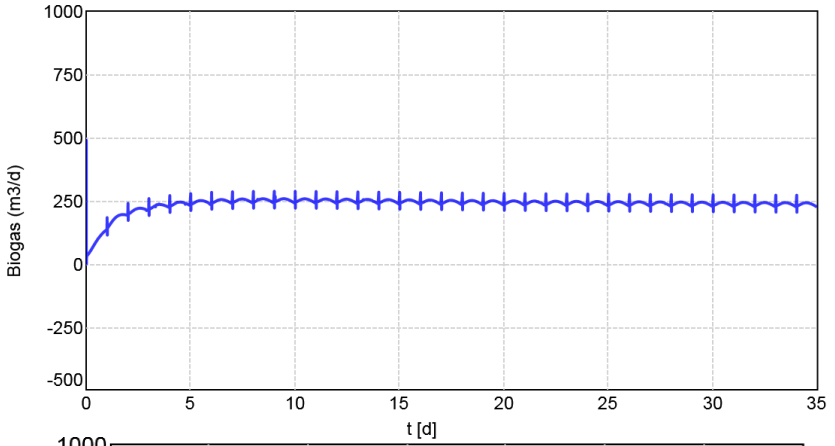


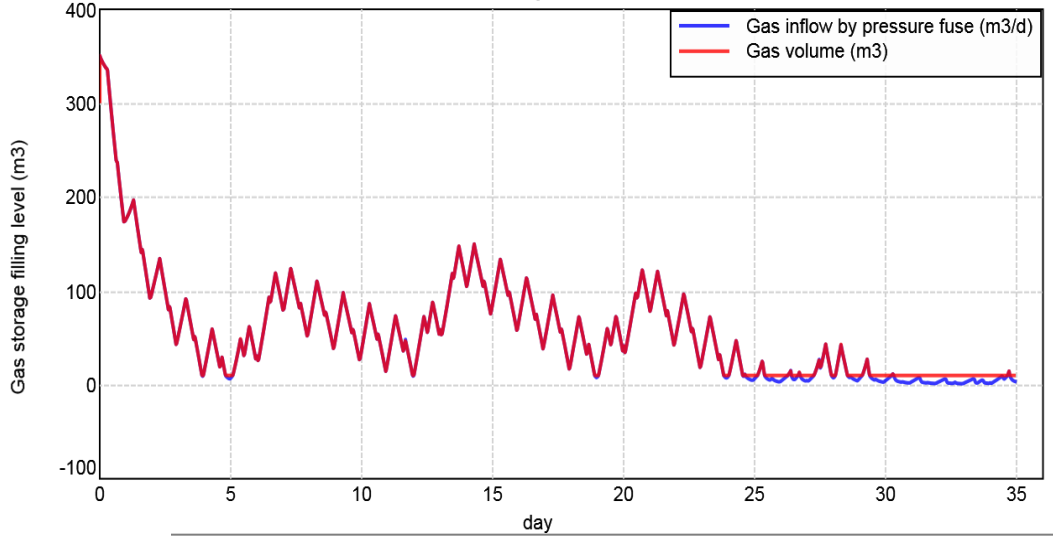
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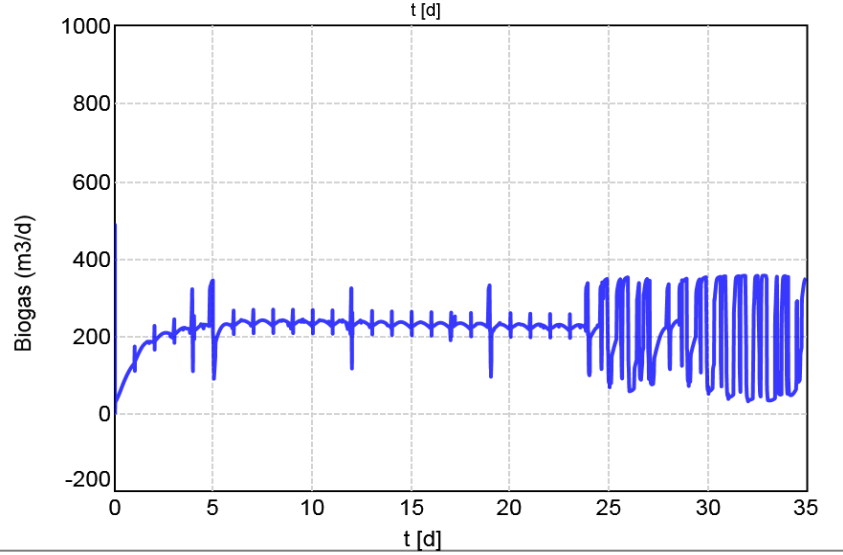
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Comparing results with constant production









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Conclusion

- Gain scheduling could handle the nonlinearity of plant by adding variable gain to the controller.
- Secondary gain scheduling with soft sensor could less variation on storage tank level and the stability of the system.
- With the proposed PI controller, demanded usage could be satisfied. Also comparing to constant production of biogas it could save $275\ m^3$ storage capacity.

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5. Irizar, I., Roche, E., Beltrán, S., Aymerich, E., & Esteban-Gutiérrez, M. (2018). Model-based design of a software sensor for real-time diagnosis of the stability conditions in high-rate anaerobic reactors – Full-scale application to Internal Circulation technology. *Water Research*, *143*, 479–491. https://doi.org/10.1016/j.watres.2018.06.055

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