Emnemodul: Advanced Process Control

01. Nov. 2022. Time: 1400 – 1700.

Answer as carefully as possible, preferably using the available space. There are in total 6 questions. Answer all questions in English.

No printed or hand-written support material is allowed. A specific basic calculator is allowed.

Problem 1 – General questions (24%)

a) The plantwide control procedure from Skogestad is divided into two parts: top-down and bottom-up approaches. Briefly describe the goal of each part.

b) Describe the main steps of the top-down procedure for plantwide control.

c) What is self-optimizing control? Cite methods for finding self-optimizing variables.

d) What is extremum seeking control? What are the main assumptions for its implementation?

e) What is the meaning of “squeeze and shift” in the context of optimal operation?

f) In the operation of a distillation column, which purity constraint is expected to be active? When is a constraint on maximum vapor reflux expected to be active?

g) What is “snowballing” in the context of recycle processes? How can you avoid it?

h) Why do we avoid pairing CVs from the regulatory layer to MVs that may saturate?

Problem 2 – Optimal process operation (16%)

Consider a process with $n_u = 2$ steady-state degrees of freedom, $n_d = 1$ disturbance that affects economics, $n_g = 1$ inequality constraint $g = u_2 - u_1 \leq 0$, and $n_y = 2$ extra available measurements. The optimal conditions for the process for different disturbance values are given by the following table:

	$\boldsymbol{d = 0.5}$	$\boldsymbol{d = 0.6}$
$\boldsymbol{g}$	0	0
$\boldsymbol{y_1}$	0.45	0.6
$\boldsymbol{y_2}$	0.4	0.52

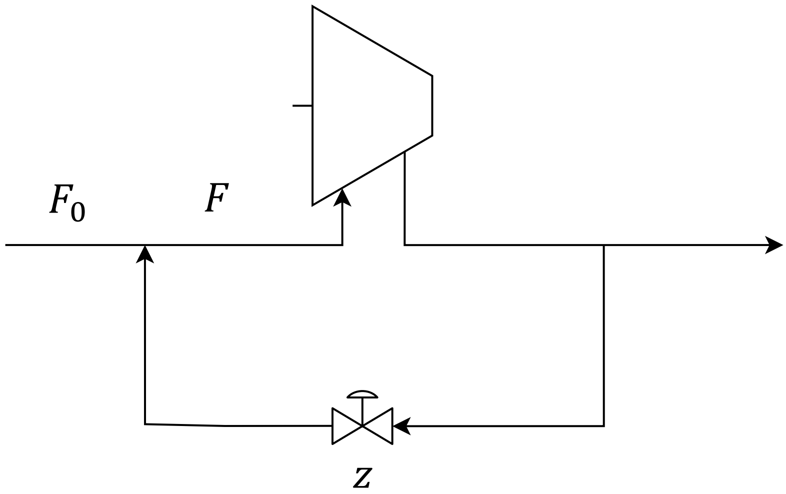
a) Analyze the optimal operation for this problem, in terms of active constraints and unconstrained DOFs. Explain why the optimal CVs are $c_1 = u_2 - u_1$ and $c_2 = Hy$.

b) Calculate the optimal sensitivity matrix F for this system. Using this, calculate the selection matrix H through the nullspace method.

c) Identification of the system was performed, and it was found that the steady-state gain from the MVs to the measurements is $G^y = \begin{bmatrix} -0.8 & -1.0 \\ 1.1 & -0.6 \end{bmatrix}$, such that $\Delta y = G^y \Delta u$. With this additional information and based on the items above, determine the gain matrix G from the MVs to the CVs for optimal operation, and determine the ideal pairing between these MVs and CVs using the steady-state RGA of the system.

Problem 3 – Anti-surge control (15%)

Consider the following anti-surge system:



In this system, the compressor must be fed a minimum flow $F \geq F_{min}$ in order to avoid abnormal operation. However, the system should also operate with the recycle valve fully closed whenever possible, in order to avoid additional compression costs. The process feed F_0 is the main disturbance for the process, and the recycle valve z is the only available MV.

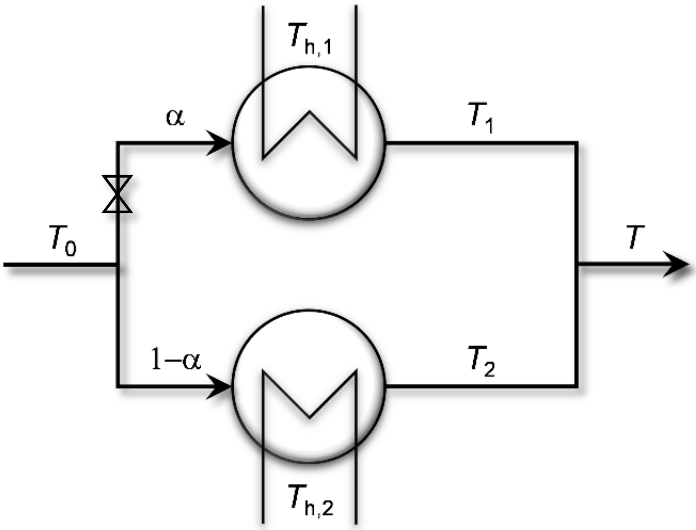
a) State the possible operating regions for optimal operation of the system, in terms of the active constraints. Are the constraints related to an MV or a CV?

b) Propose a control structure that can operate optimally in all regions.

c) Can the system operate optimally in all regions without the use of advanced control elements? Why?

Problem 4 – Heat exchanger networks (15%)

Consider the optimal operation of the following heat exchanger network:



The objective of the operation is to maximize the outlet temperature ($J = T$). In Exercise 1 we derived a simple analytical expression for the cost gradient, $J_u = \frac{1}{2}\left(\frac{(T_2-T_0)^2}{T_{h,2}-T_0} - \frac{(T_1-T_0)^2}{T_{h,1}-T_0}\right)$, with the MV being the split ratio α.

Assume that the system is subject to a constraint on the maximum allowed temperature on the top branch, $T_1 \leq T_{max}$, which can be active or inactive due to disturbances.

a) What are the possible operating regions for optimal operation? What are the corresponding CVs for each region?

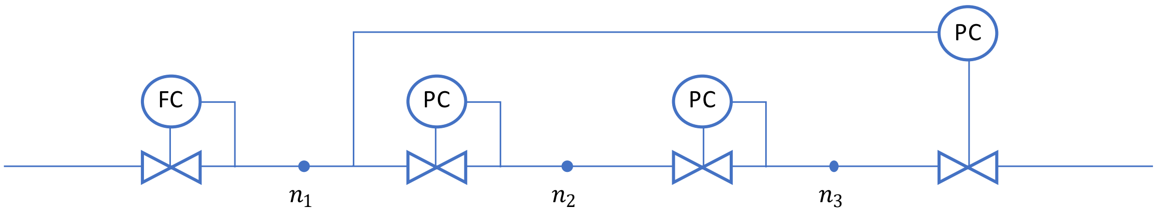
b) Propose a feedback control structure that operates optimally in all scenarios.

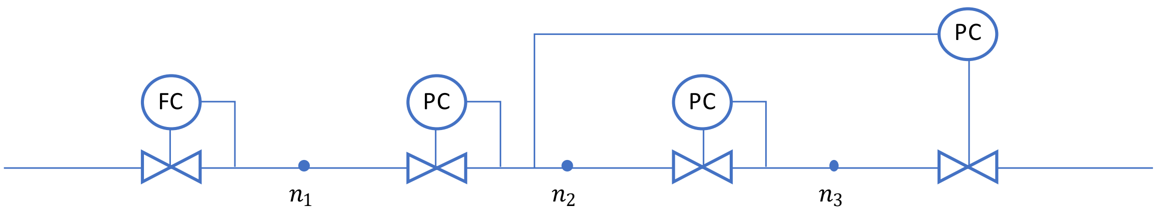
c) Why is $c = T$ not a good self-optimizing variable?

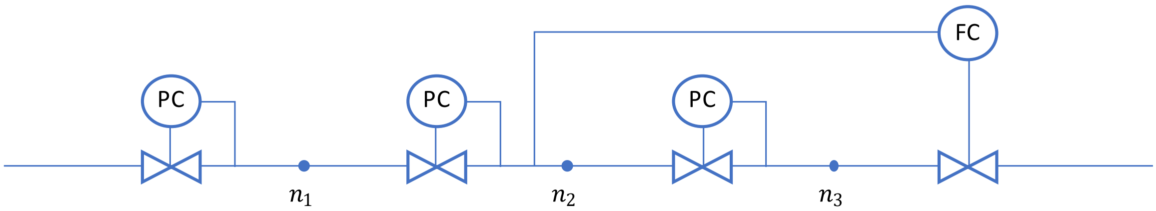
Problem 5 – TPM and inventory control (10%)

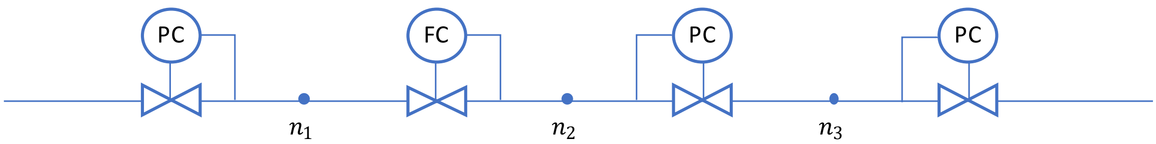
a) What are the conditions for local consistency and global consistency of an inventory control structure? How are they related?

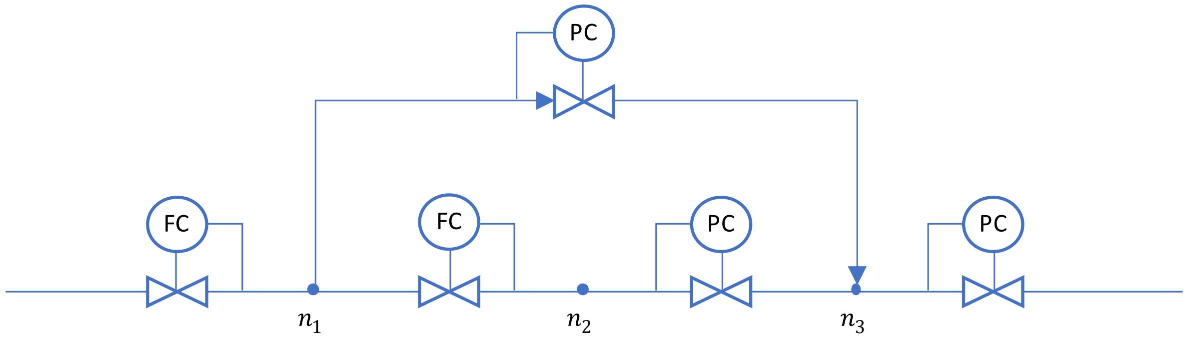
b) Analyze the 6 control structures below. Indicate the location of the TPM and if they are locally and/or globally consistent. Justify your answers.







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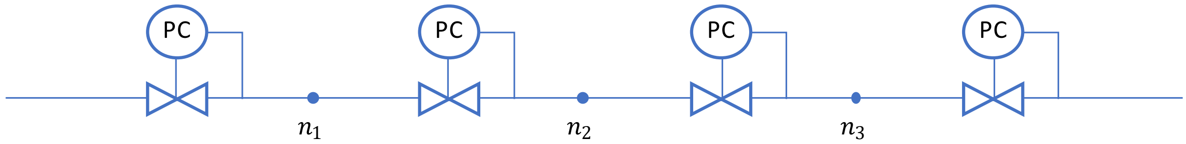
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Problem 6 – Controller tuning (20%)

Consider the system described by the following model, with time constants in seconds:

$$y = \frac{2\,(-0.5\,s + 1)}{(5\,s + 1)(2\,s + 1)}\,u + \frac{8\,e^{-2\,s}}{(5\,s + 1)(10\,s + 1)}\,d_1 + \frac{1}{2\,s + 1}\,d_2$$

We wish to control y through feedback by manipulating u. The measurement of d_1 is available with a delay of 1 second, and we wish to use this measurement of d_1 to improve control performance.

a) What is the control structure that should be used in this case? Draw the block diagram, along with all process transfer functions, of the proposed control structure.

b) Tune the feedback controller from the structure you proposed using the SIMC rules. Use the half-rule when necessary to reduce the model to a first order plus time delay form and choose the respective tuning parameter such that tight control is achieved.

c) Find the ideal controller for rejecting the effect of d_1 on y. Is this controller realizable? If not, propose a realizable solution.

d) If the measurement of d_1 is subject to an additional delay of 10 seconds, what would that mean for the item above?