AVT | SVT | RWTH Aachen | 52074 Aachen

Systemverfahrenstechnik

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Bonus Point Programming Exercise 1

Deadline: December 1, 2020, 24:00 h

Applied Numerical Optimization

Wintersemester 2020/2021

Rules for bonus point exercises

- Please work on the bonus point exercise in groups of 2, 3 or 4 students.
- **One member per group** should submit the solution (typically, one or more MATLAB '.m' files) on Moodle before the deadline. The names and enrollment-numbers (or TIM-number, in case no enrollment-number is available) of the group members should be written as comments at the top of the '.m' file.
- Please take care that your code is well-documented (through comments within the source code) and executes out of the box. The results of the first bonus points exercise will be published by December 20, 2020, on RWTHmoodle.

Exercise (Linear Programming)

Recall the optimization problem from Exercise 1 (see Figure 1).
Relevant data is shown in Tables 1, 2, 3 and 4.

1. The collection of optimization variables to be considered is : $\boldsymbol{x}^T = (P_1,\ P_2,\ PP,\ EP,\ Power,\ Fuel,\ C,\ I_1,\ I_2,\ HE_1,\ HE_2,\ LE_1,\ LE_2,\ BF_1,\ BF_2,\ HPS,\ MPS,\ LPS)$, where $\boldsymbol{x} \in \mathbb{R}^{18}$.
2. The *objective function* comprises the sum of all operational costs. Still, we have to take care of the 'demand penalty', namely, only in the case the additionally purchased energy (EP) does not exceed the basic power (12 MW), the 'demand penalty' comes into play. Thus, the complete formulation of this optimization problem comprises these two cases:
   (a) $J(\boldsymbol{x}) = 1.5 \cdot 10^{-6}\, Fuel + 0.008\, C + 0.02\, PP + 0.05 EP + 0,001(12000 - EP)$
   for $0 \leq EP \leq 12000\, [kW]$.

(b) $J(\boldsymbol{x}) = 1.5 \cdot 10^{-6}\, Fuel + 0.008\, C + 0.02\, PP + 0.05 EP$
for $EP \geq 12000\, [kW]$.

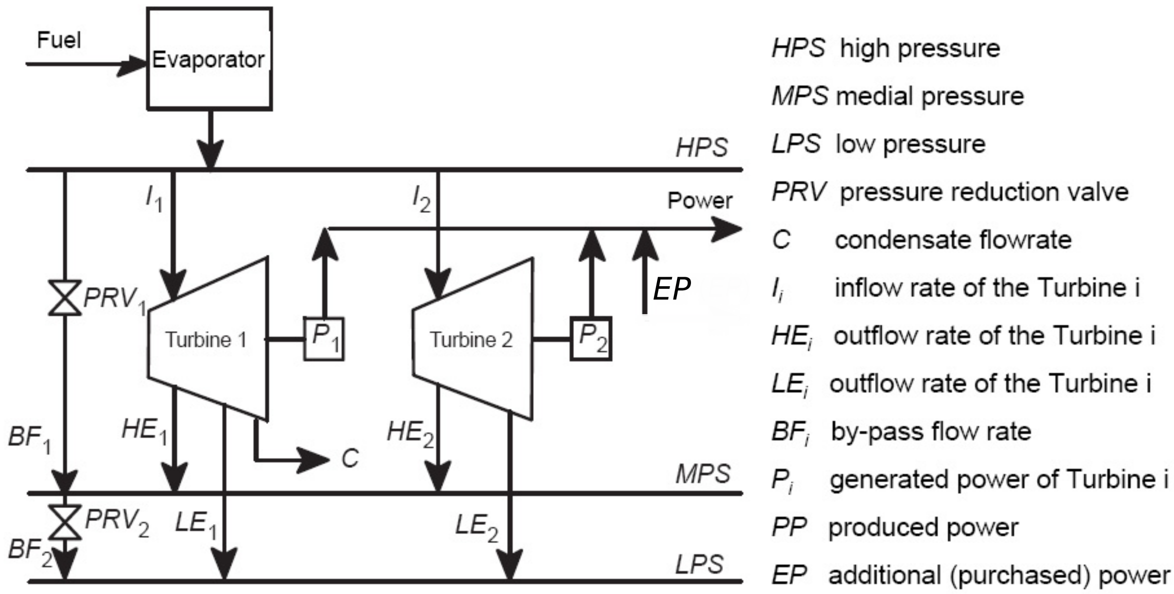

Figure 1: System from Exercise 1

Table 1: Description of turbines

Parameters	Turbine 1	Turbine 2
Max. power [kW]	6250	9000
Min. power [kW]	2500	3000
Max. inflow [kg/h]	87 000	110 000
Max. LPS-flow [kg/h]	-	64 000
Max. condensate flow [kg/h]	28 000	-
Max. internal flow [kg/h]	60 000	-

Table 2: Vapor data

Vapor stage	Enthalpy [kJ/kg]
HPS	3163
MPS	2949
LPS	2911
Condensate (Water)	449

Table 3: System requirements

Resource	Demand
MPS	123 000 kg/h
LPS	45 000 kg/h
Electrical power	24.5 MW

Table 4: Energy data

Fuel cost [€/10^6kJ]	1.5
Evaporator efficiency	0.75
Condensate loss [€/Kg]	0.008
Produced electrical power [€/kWh]	0.02
Purchased electrical power [€/kWh]	0.05
Demand penalty [€/kWh]	0.001
Basic power [MW]	12

3. Model:

Mass balances:

$$HPS = I_1 + I_2 + BF_1 \quad \text{(MB1)}$$
$$I_1 = HE_1 + LE_1 + C \quad \text{(MB2)}$$
$$I_2 = HE_2 + LE_2 \quad \text{(MB3)}$$
$$HE_1 + HE_2 + BF_1 = BF_2 + MPS \quad \text{(MB4)}$$
$$LPS = LE_1 + LE_2 + BF_2 \quad \text{(MB5)}$$

Energy balances:

$$3163 I_1 = 2949 HE_1 + 2911 LE_1 + 449 C + 3600 P_1 \quad \text{(EB1)}$$
$$3163 I_2 = 2949 HE_2 + 2911 LE_2 + 3600 P_2 \quad \text{(EB2)}$$
$$PP = P_1 + P_2 \quad \text{(EB3)}$$
$$Power = PP + EP \quad \text{(EB4)}$$
$$\text{Enthalpy\_of\_HPS} \cdot HPS = \text{Evaporator\_Efficiency} \cdot Fuel \quad \text{(EB5)}$$

P_1 and P_2 are in kW: $1kW = 1\frac{kJ}{s} = 3600\frac{kJ}{h}$

4. Inequality constraints:

2500	$\leq$	P_1	$\leq$	6250	(IC1)
		I_1	$\leq$	87000	(IC2)
		C	$\leq$	28000	(IC3)
		$I_1 - HE_1$	$\leq$	60000	(IC4)
3000	$\leq$	P_2	$\leq$	9000	(IC5)
		I_2	$\leq$	110000	(IC6)
		LE_2	$\leq$	64000	(IC7)
		MPS	$\geq$	123000	(IC8)
		LPS	$\geq$	45000	(IC9)
		$P_1 + P_2 + EP$	$\geq$	24500	(IC10)

all optimization variables shall be non-negative, i.e., ≥ 0 (IC11)

either case a)	EP	$\leq$	12000	(IC12a)
or case b)	EP	$\geq$	12000	(IC12b)

Complete optimization problem

case a)

$$\begin{aligned} \min_{\boldsymbol{x}} \quad & J(\boldsymbol{x}) \\ \text{s.t.} \quad & \text{(MB1)-(MB5)} \\ & \text{(EB1)-(EB5)} \\ & \text{(IC1)- (IC11)} \\ & \text{(IC12a)} \end{aligned}$$

case b)

$$\begin{aligned} \min_{\boldsymbol{x}} \quad & J(\boldsymbol{x}) \\ \text{s.t.} \quad & \text{(MB1)-(MB5)} \\ & \text{(EB1)-(EB5)} \\ & \text{(IC1)- (IC11)} \\ & \text{(IC12b)} \end{aligned}$$

Task

- **Implement and solve the optimization problem with the MATLAB solver `linprog`.**
- **Is the demand penalty active or not?**
- **Write down the units of all the optimization variables next to their names (as comments in the same '.m' file) e.g. % <variable name> - <unit>**

Hint:

- *The optimal function value is approximately 1944 [€/hour].*