Multivariable Control Systems

Laboratory Course:

Lab 2: Electric Power Networks Control

Course Supervisor: Prof. Sandra Hirche

Laboratory course resonsible: M.Sc. Vahid Mamduhi

Lehrstuhl für Informationstechnische Regelung
Technische Universität München

2nd Laboratory-Task preparation

- It is recommended to make a group up to four students
- Each group should submit a pdf-format report in English along with the Matlab codes in one zip file before the given deadline
- Send your hand-in package to the address *mh_mamduhi@tum.de*
- The deadline is on 10.01.2015

Outline

- About the lab course
- Lab two: Electric power network control
  - ✓ Electric power networks
  - ✓ Voltage control
  - ✓ Frequency control
- Matlab® control toolbox
- Tasks

Lab two: Electric Power Network

Power networks:

- Geographically distributed
- Large-scale systems
- Multi-input multi-output
- Interconnected systems

Generated electricity:

- Voltage magnitude
- Frequency
- Wave shape

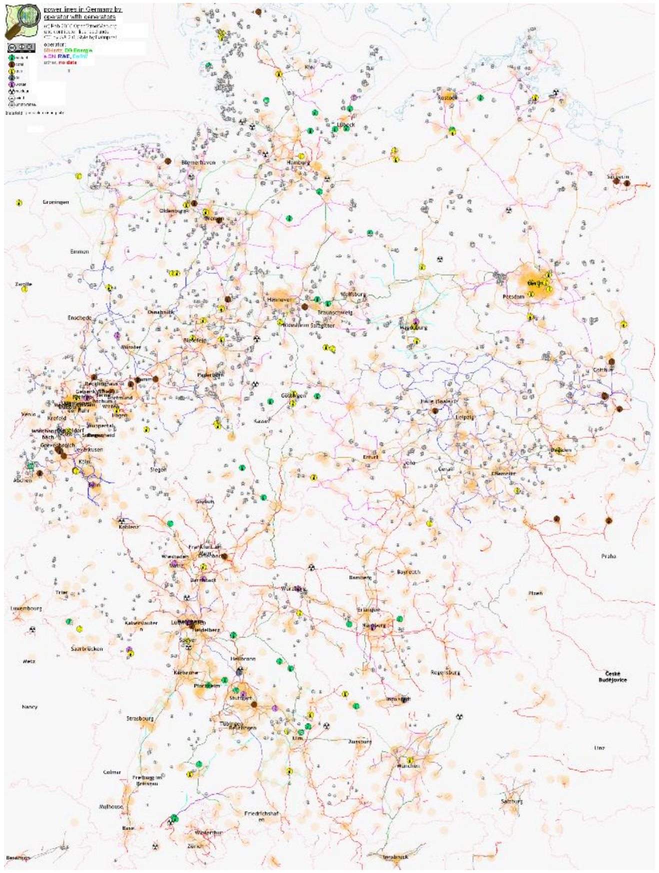
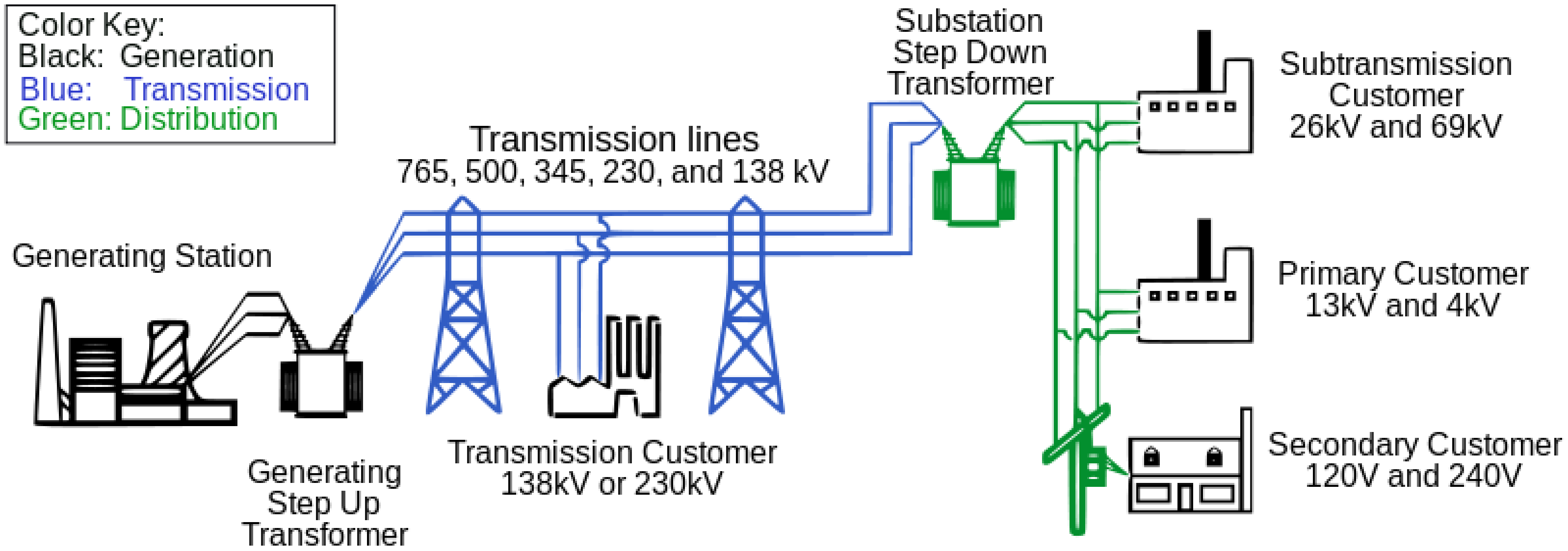


Fig. 1: Power transmission grid in Germany

Lab two: Electric Power Network

From generation to distribution:



Three phases:

- Generation
- Transmission*
- Distribution

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Main Objective:

Maintain the balance between generated power and load power consumption:

- ✓ No frequency fluctuation
- ✓ No voltage fluctuation*
- ✓ No wave shape deviation

Approach:

- ✓ Frequency Control
- ✓ Voltage Control*

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Voltage control:

Regulation of infeed node voltages such that the output voltages track pre-determined set values

Factors influencing the voltages in a power grid:

- ✓ Terminal voltages of synchronous machines
- ✓ Transmission lines impedance
- ✓ Turn ratio of transformers

Control approach:

- ✓ Decentralized control

Lab two: Electric Power Network

Linearized multivariable model of power network:

$$\dot{x}_i = A_i x_i + \sum_{j \neq i} A_{ij} x_j + B_i u_i$$

$$y_i = C_i x_i$$

- ✓ $A_i \rightarrow$ Local dynamics
- ✓ $A_{ij} \rightarrow$ Interconnection between power plants
- ✓ $u_i \rightarrow$ Terminal voltage regulator
- ✓ $y_i \rightarrow$ Sensory measurements

Matlab® control toolbox

Getting started with Matlab®

- Type `help` <*function name*> to get help from Matlab®

Sample Matlab®codes for the laboratory:

1. Basic concepts (transfer functions, poles, zeros, eigen values, time/frequency response, observability/controllability)
2. LTI systems data extraction (state-space model, system margins, bode diagram)
3. Decentralized control design (RGA analysis, I/O pairings, PI control design)
4. Search methods (coefficient search, constrained loops)

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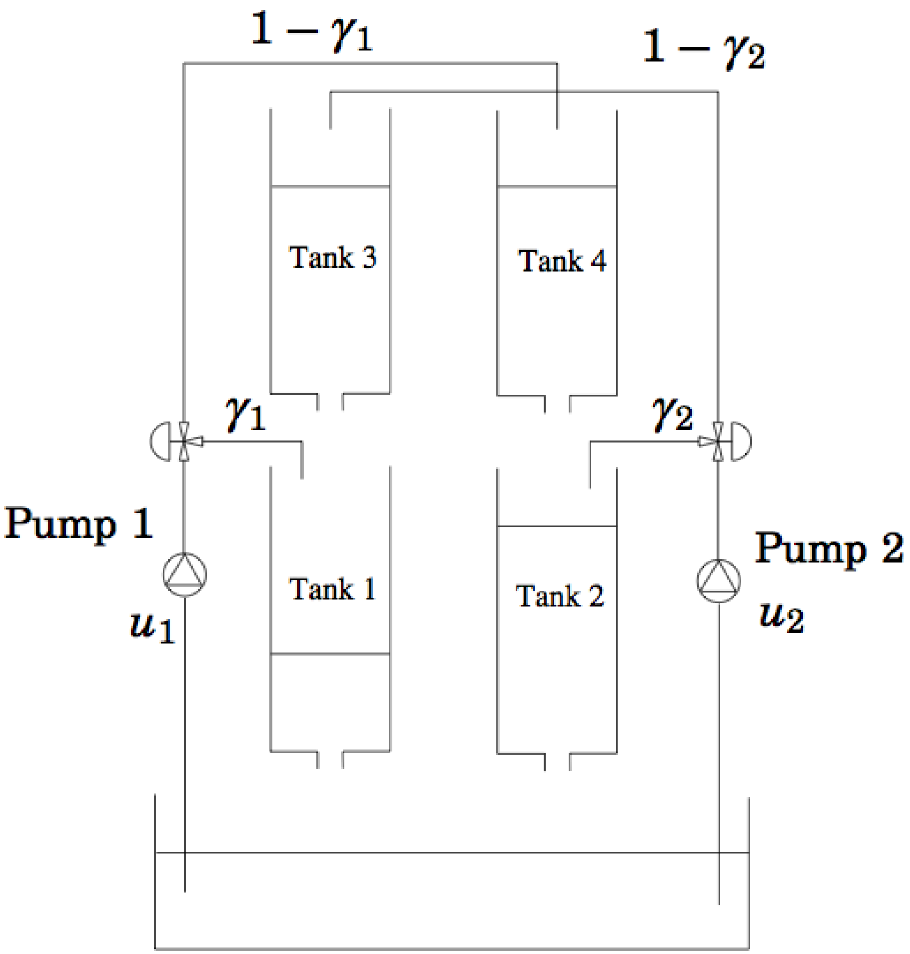
Four water tanks model:

- ✓ Two-input two-output model
- ✓ Two control inputs (pump)
- ✓ Two controlled outputs (lower tanks water levels)



Matlab® control toolbox

Four water tanks model:

- ✓ Input signal (U): pump voltages
- ✓ Output signal (Y): water level in lower tanks
- ✓ Valves: divide the upper and lower tank water

Linear multivariable model:

$$Y(s) = \begin{bmatrix} Y_1(s) \\ Y_2(s) \end{bmatrix} \quad , \quad U(s) = \begin{bmatrix} U_1(s) \\ U_2(s) \end{bmatrix}$$

$$G(s) = \begin{bmatrix} g_{11}(s) & g_{12}(s) \\ g_{21}(s) & g_{22}(s) \end{bmatrix}$$

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Linearized model of four-tank process:

$$B = \begin{pmatrix} 0.174 & 0 \\ 0 & 0.02582 \\ 0 & 0.09037 \\ 0.1044 & 0 \end{pmatrix}, C = \begin{pmatrix} 0.2 & 0 & 0 & 0 \\ 0 & 0.2 & 0 & 0 \end{pmatrix}$$

$$A = \begin{pmatrix} -0.0564 & 0 & 0.02572 & 0 \\ 0 & -0.00889 & 0 & 0.00365 \\ 0 & 0 & -0.0257 & 0 \\ 0 & 0 & 0 & -0.0213 \end{pmatrix}$$

$$\dot{x} = Ax + Bu$$
$$y = Cx$$

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Basic control commands, and data extraction:

```
sys=ss(A,B,C,D)
G=tf(sys)
ssdata(sys)
pole(G)
zero(G)
pzmap(sys)
sigma(sys)
[V,D]=eig(A)
```

```
step(sys)
impulse(sys)
bode(sys)
margin(sys)
nyquist(sys)
ctrb(A,B)
obsv(A,C)
rank(A)
```

Matlab® control toolbox

Tasks:

1. Compute the relative gain array at a given frequency
2. Design a decentralized PI control for the four-tank process such that the phase margin is ${}^{\pi}/_{3}$ and the cross-over frequency is $0.1\ {}^{rad}/_{s}$.
3. Analyze the frequency response of the loop gain to see how the decentralized control behaves
4. Search for the coefficients of the characteristic polynomial with and without constraints.
5. Dynamic decoupling control at the same phase margin and cross-over frequency

Matlab® control toolbox

Matlab® codes…

References

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