CIRED
ROME, ITALY
12-15 JUNE 2023

Technology Arts Sciences
TH Köln

Decentralized Grid Control Using Power Grid State Estimation

Eberhard Waffenschmidt, TH-Köln, Germany
Markus de Koster, TH-Köln, Germany
Christian Hotz, TH-Köln, Germany
Sergej Baum, TH-Köln, Germany
Ingo Stadler, TH-Köln, Germany

Our Idea

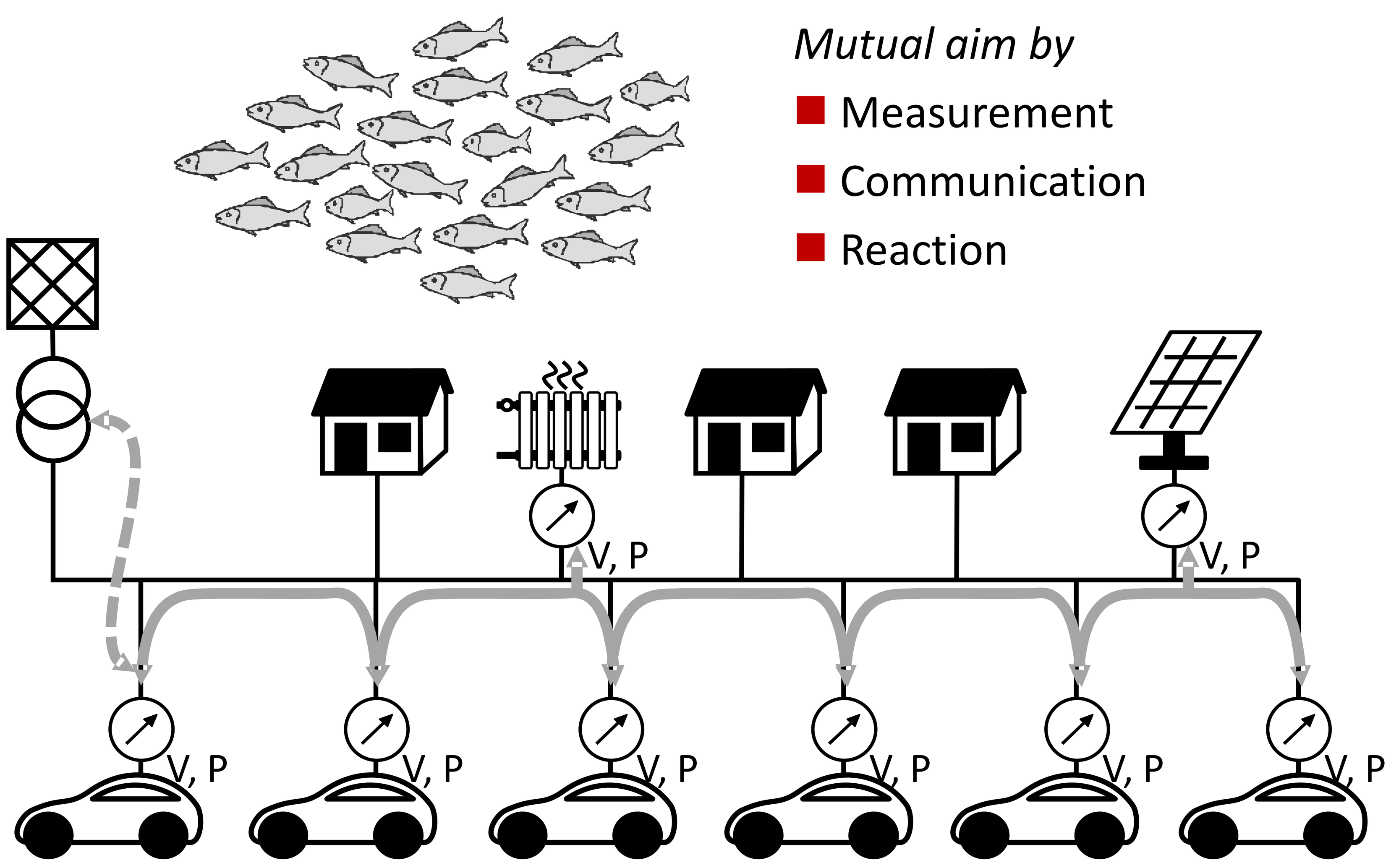
Decentralized control

- *Aim of control*: No grid overload
- For variable loads
- Loads communicate
  - to share power budget
  - to share measurements
  - to enable grid topology estimation, grid state estimation
- Grid state estimation allows variable power budget

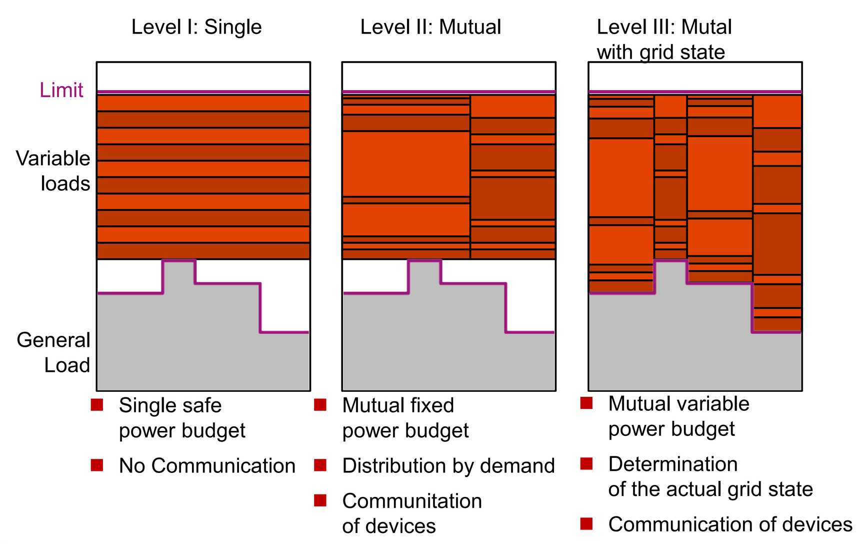
Swarm Grid

Mutual aim by

- Measurement
- Communication
- Reaction



Three levels control of power budget



Benefits

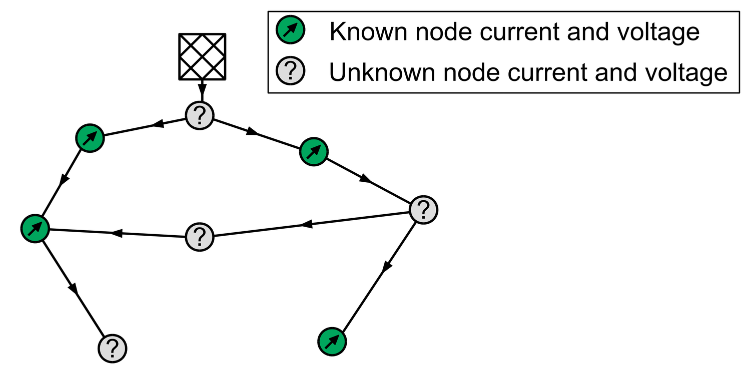
- Less grid extension needed
- No investment for central controller needed
- Fast grid use extension
- Resilient
- No discrimination of loads

How does it work

Node voltages and currents:

Easy-Peasy:

Known nodes n = m unknown nodes



Setup equation system with admittance matrix:

Coefficients known from line impedances

$$\begin{pmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & a_{46} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & a_{56} \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \end{pmatrix} \cdot \begin{pmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \\ U_5 \\ U_6 \end{pmatrix}$$

Known node currents and voltages (I_1, I_2, I_3; U_1, U_2, U_3)

Unknown node currents and voltages (I_4, I_5, I_6; U_4, U_5, U_6)

Sort unknown to left and known to right

$$\begin{aligned} -a_{14} \cdot U_4 - a_{15} \cdot U_5 - a_{16} \cdot U_6 &= -I_1 + a_{11} \cdot U_1 + a_{12} \cdot U_2 + a_{13} \cdot U_3 \\ -a_{24} \cdot U_4 - a_{25} \cdot U_5 - a_{26} \cdot U_6 &= -I_2 + a_{21} \cdot U_1 + a_{22} \cdot U_2 + a_{23} \cdot U_3 \\ -a_{34} \cdot U_4 - a_{35} \cdot U_5 - a_{36} \cdot U_6 &= -I_3 + a_{31} \cdot U_1 + a_{32} \cdot U_2 + a_{33} \cdot U_3 \end{aligned}$$

U_4, U_5 and U_6 can be determined by inversion of the left partial matrix

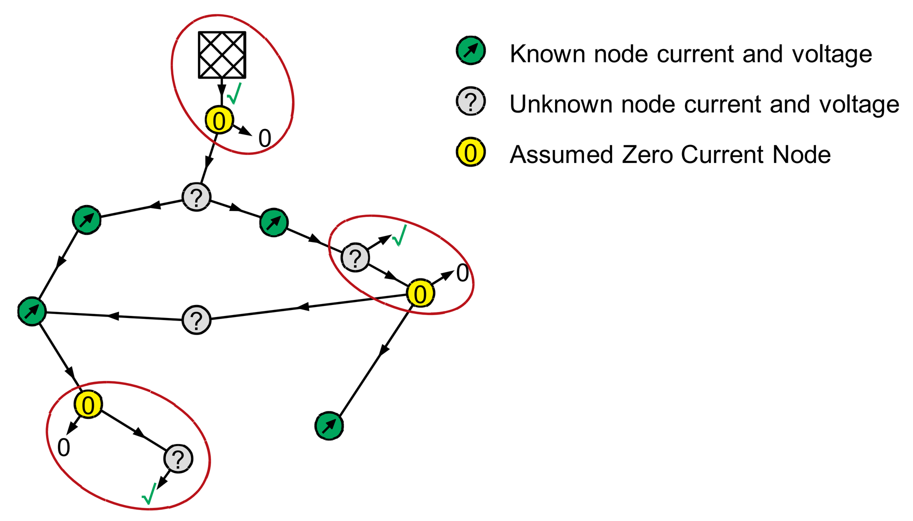
$$\begin{aligned} -a_{44} \cdot U_4 - a_{45} \cdot U_5 - a_{46} \cdot U_6 + I_4 &= +a_{41} \cdot U_1 + a_{42} \cdot U_2 + a_{43} \cdot U_3 \\ -a_{54} \cdot U_4 - a_{55} \cdot U_5 - a_{56} \cdot U_6 + I_5 &= +a_{51} \cdot U_1 + a_{52} \cdot U_2 + a_{53} \cdot U_3 \\ -a_{64} \cdot U_4 - a_{65} \cdot U_5 - a_{66} \cdot U_6 + I_6 &= +a_{61} \cdot U_1 + a_{62} \cdot U_2 + a_{63} \cdot U_3 \end{aligned}$$

Then I_4, I_5 and I_6 can be calculated

- For each known variable (U or I) one unknown variable (U or I) can be calculated

Not so easy:

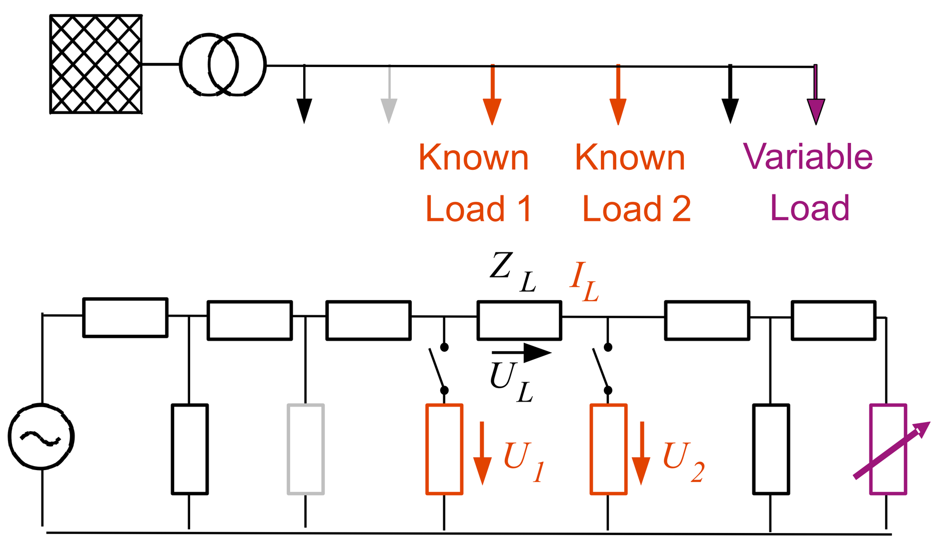
Known nodes n < m unknown nodes *or* Ambiguous arrangements



Solution:

- Select (m – n) nodes and assume a node current
- For worst case:
  - Select nodes, which are *not* at the end
  - Assume node current = 0
  - If ambiguous, calculate all cases
- Each Zero Current Node adds one variable to the equation system
- Equation system is solvable, proceed like before.

Line currents:

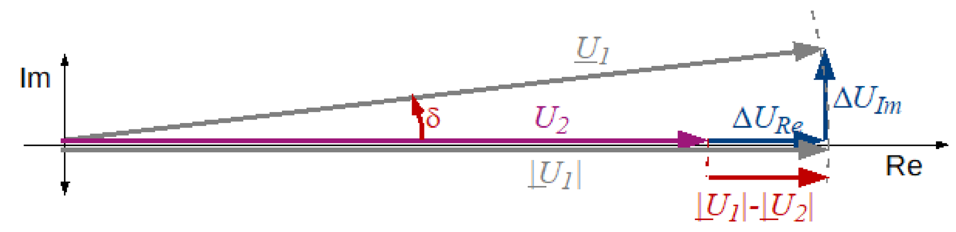


Solution:

- Use node voltages from state estimation and
- Ohm's law
- to calculate line currents

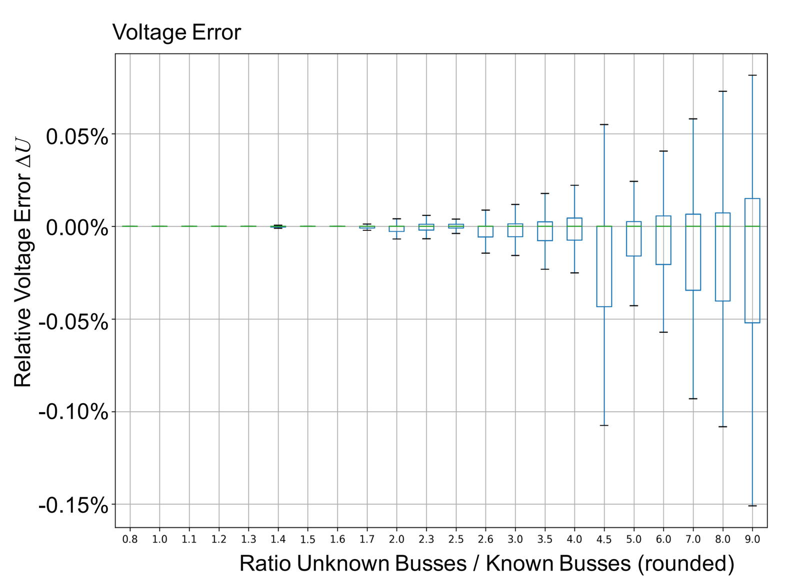
Problem:

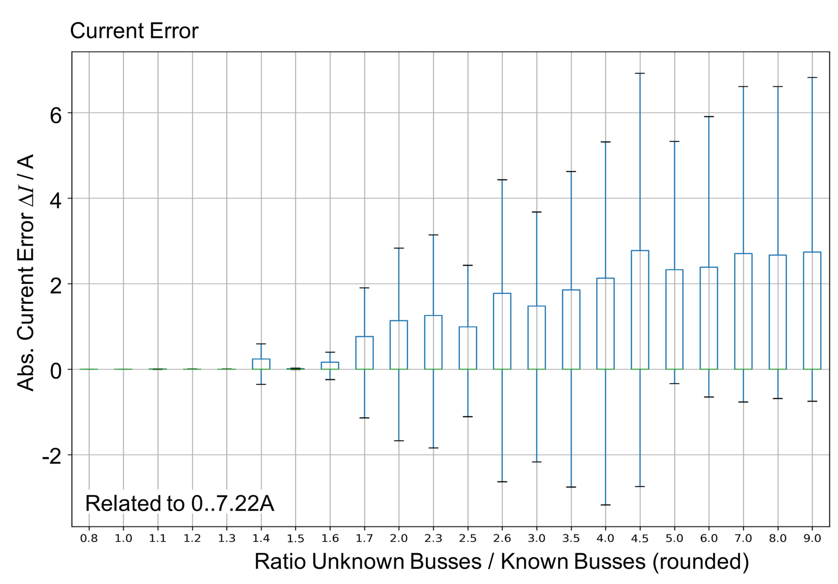
- Voltages and currents are complex numbers
- Only amplitude is measured



What errors do we get

Node voltages and currents: Error from zero current assumptions



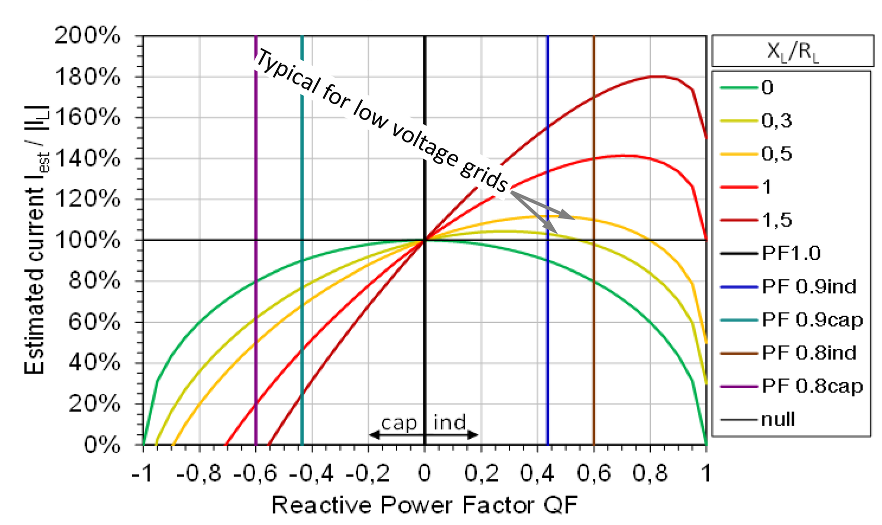


- All errors on the "safe side"
- Node voltages: Far below Errors < 0.15%
- Node currents: Large errors due to zero current assumption
- No significant errors for ratio of unknown to known busses < 4

- Up to 20589 arbitrary grids simulated and estimated
- From 4 nodes to 19 nodes
- Varying topologies and combinations of node types
- Only radial topologies
- Reference voltages and currents for all nodes from grid simulation

Note: Previous Data was not correct due to programming error

Line currents: Error without phase information



- For low voltage grids:
  - Low reactive impedance
  - Inductive currents
- => Estimation error <10%

Contact:
Eberhard Waffenschmidt
TH Köln (University of Applied Sciences)
Betzdorferstraße 2, 50679 Köln, Deutschland (Germany)
Tel. +49 221 8275 2020
eberhard.waffenschmidt@th-koeln.de
https://www.th-koeln.de/personen/eberhard.waffenschmidt/

This research project has received funding from the Electronic Components and Systems for European Leadership Joint Undertaking under grant agreement No. 876868. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Germany, Netherlands, Spain, Italy, Slovakia