Foto: Martin Braun

Digitalization in Electric Distribution Grids – Technological Trends, Opportunities and Challenges

Name: Prof. Dr. sc. Andreas Ulbig (Inputs by Franziska Tischbein, Philipp Linnartz)
Chair of Active Energy Distribution Grids (IAEW)
RWTH Aachen University

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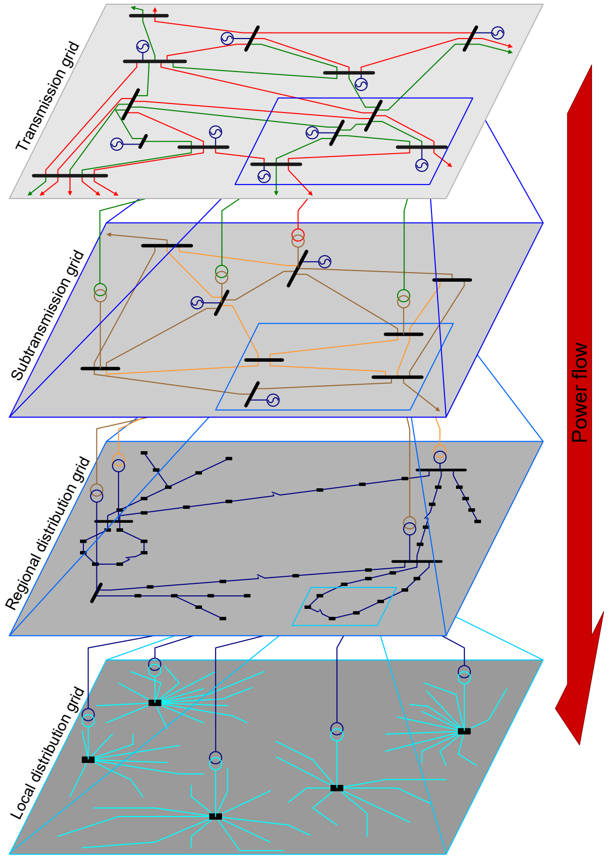
Digital and Smart – Easier said than done

Transmission grid

Subtransmission grid (high voltage)

Distribution grids



high transparency in the transmission grid

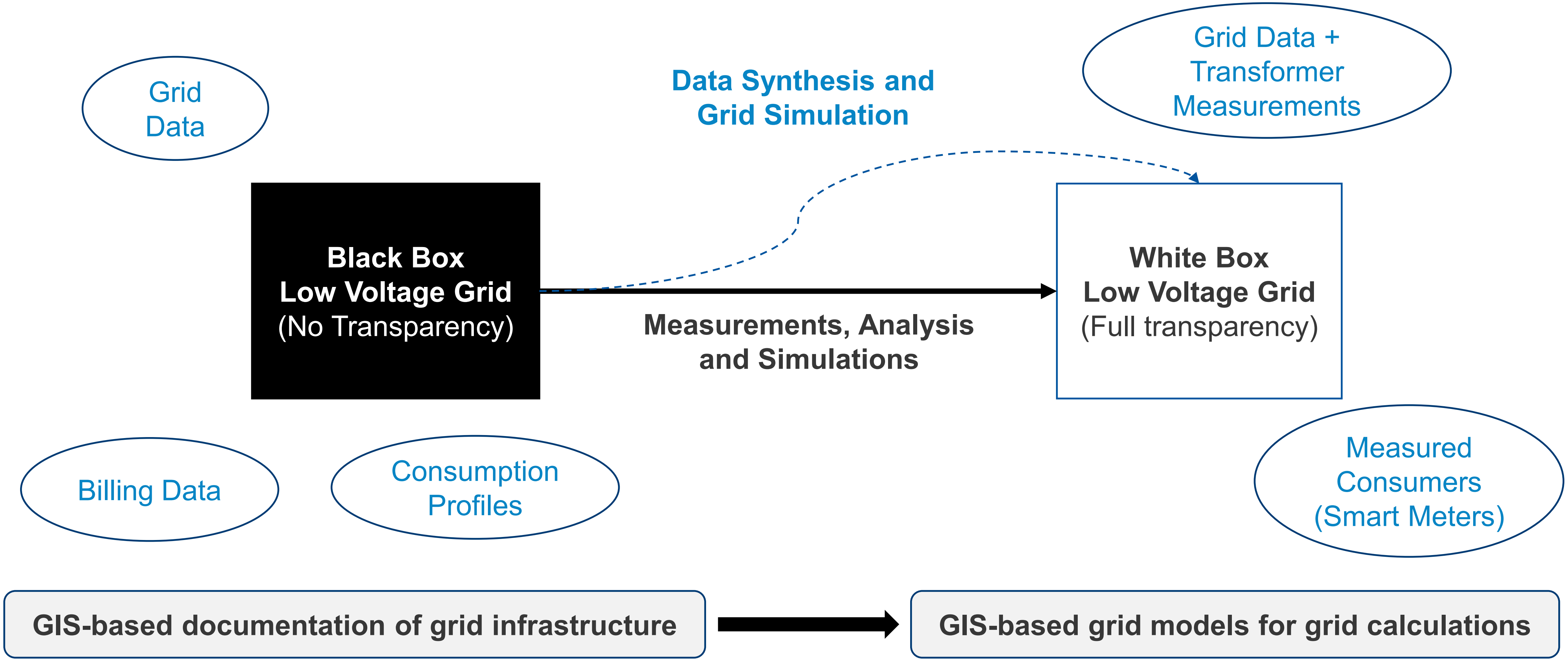
100+ grid elements
6’700 km cables (CH)

Lacking transparency in the distribution grid

100’000+ grid elements
(cables, transformers, generators, users)
250’000+ km cables (CH)

- High transparency in the transmission grid (5%)
- No insight into the lowest voltage levels (grid behavior, bottlenecks, ...)

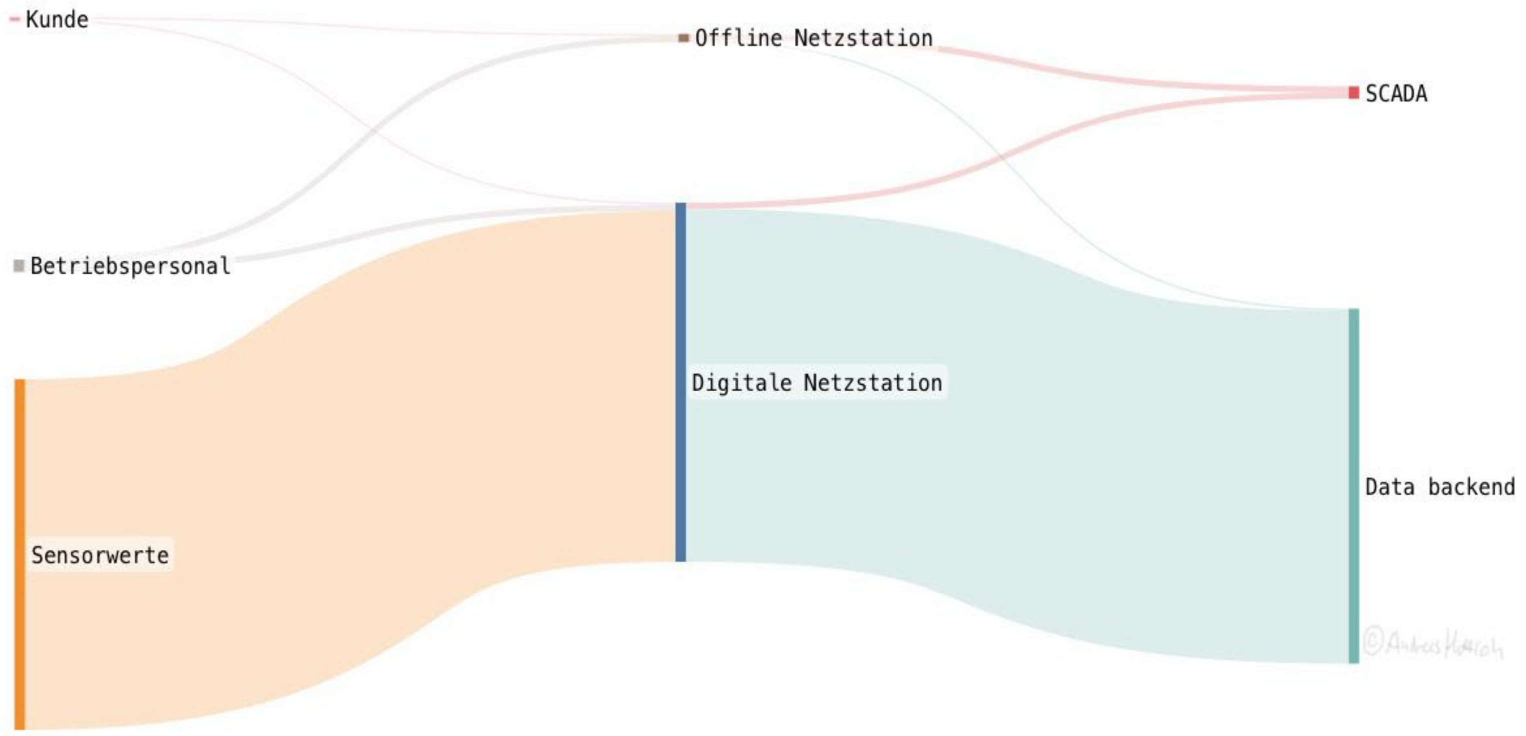
Grid Transparency Enables Active Grid Operation – Incremental path from ‘Black Box' to ‘White Box'



Digitalization in Active Distribution Grids – The Coming Sensor Data Deluge

Trend – Digital & Smart Secondary Substations

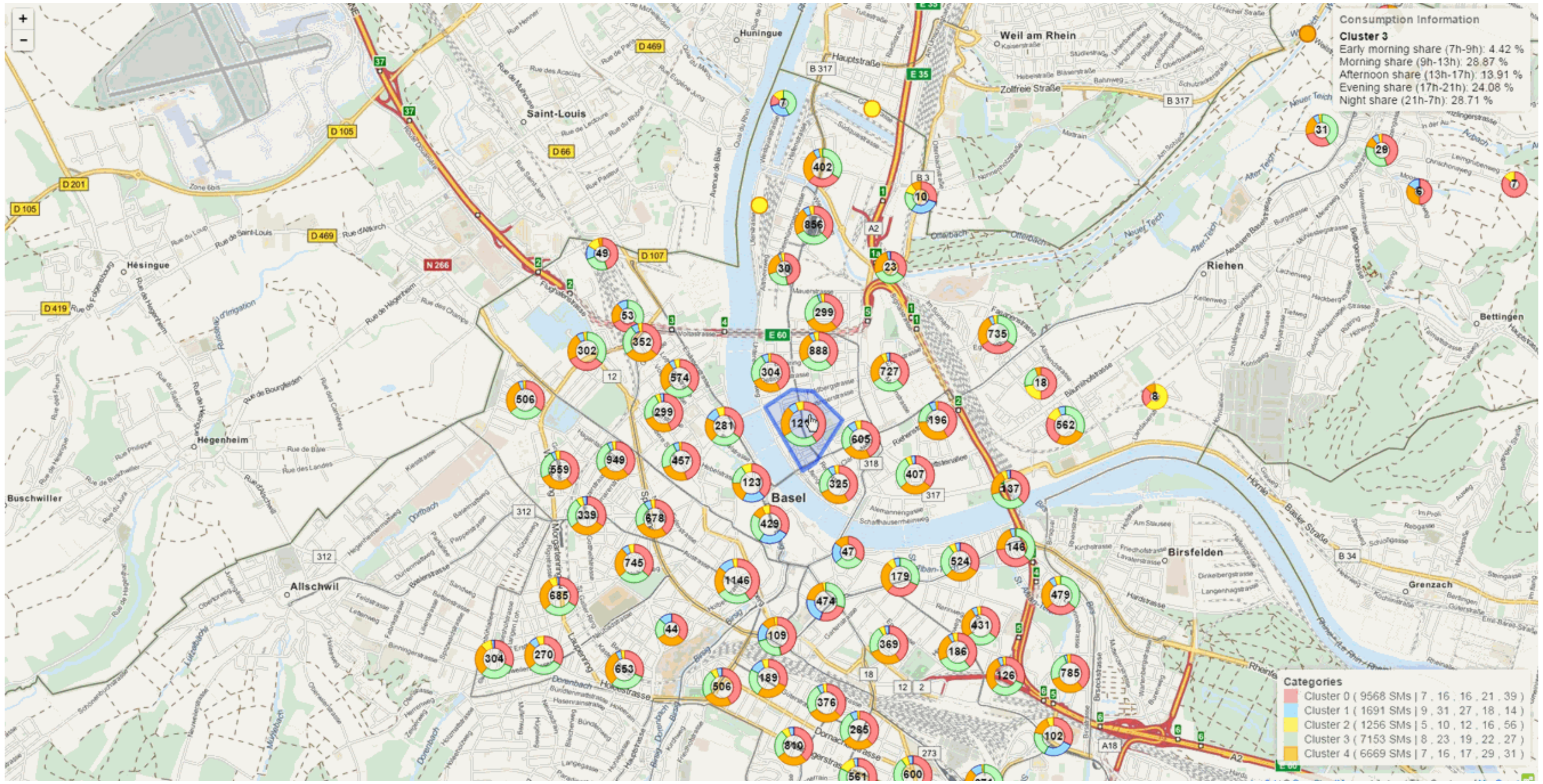
Sankey Diagram for Energy Data – Comparing Data Streams



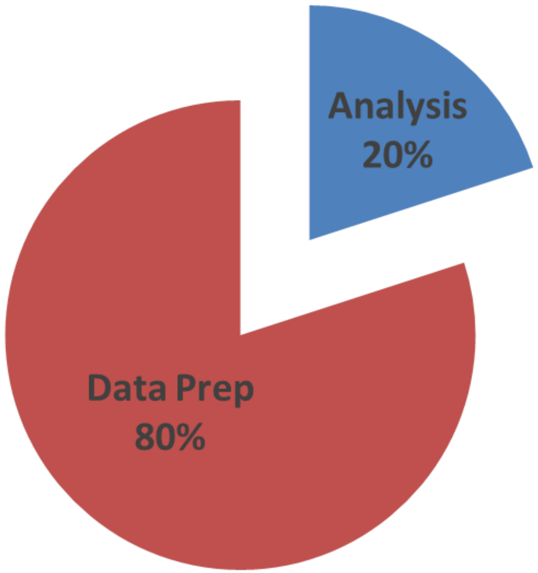
Credits: Figures by Andreas Hettich (NetzeBW)

- **Analog secondary substation – 1 data point per year (only measured variable: peak loading)**
- **Digital secondary substation – 1’000’000+ data points per year (per measured variable, 30 second sampling)**

Smart Meter Data Analytics in City of Basel

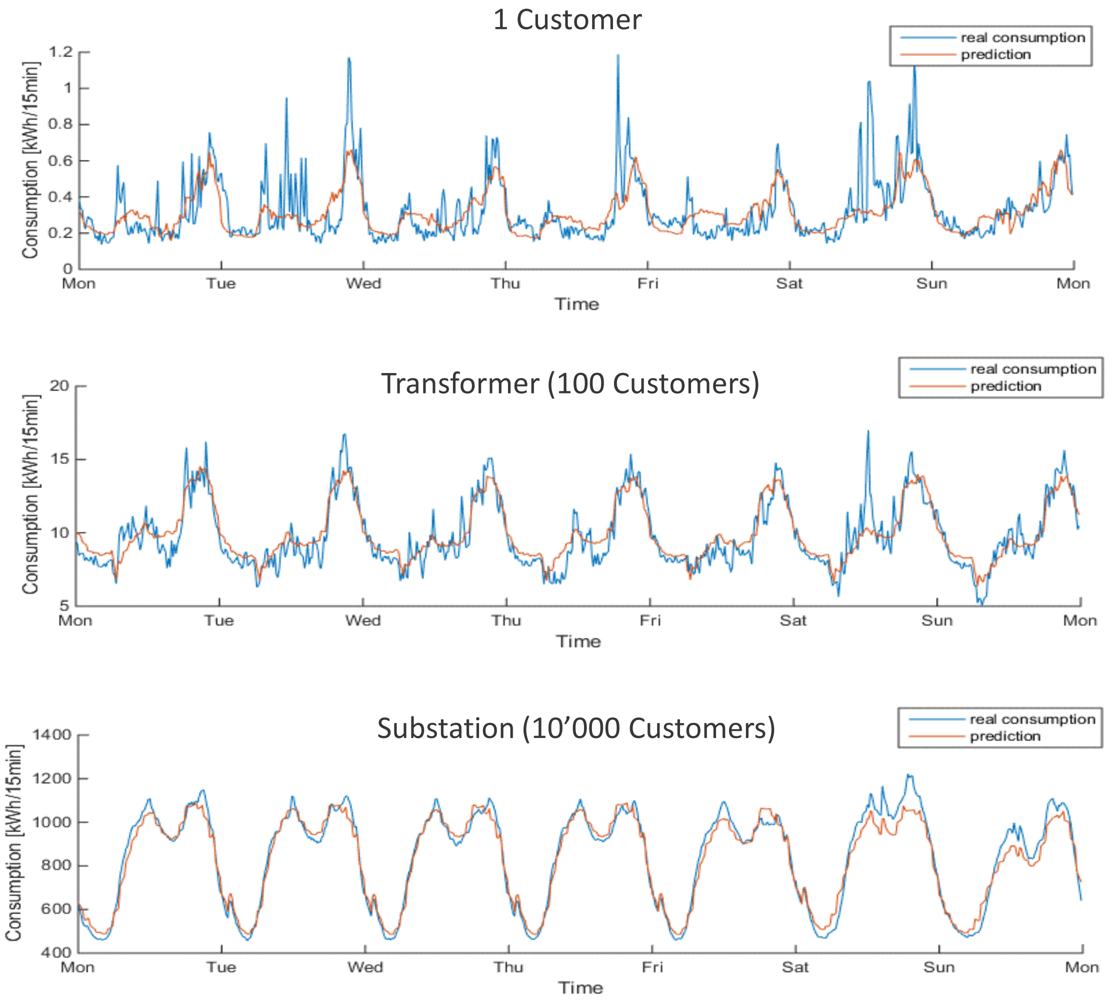


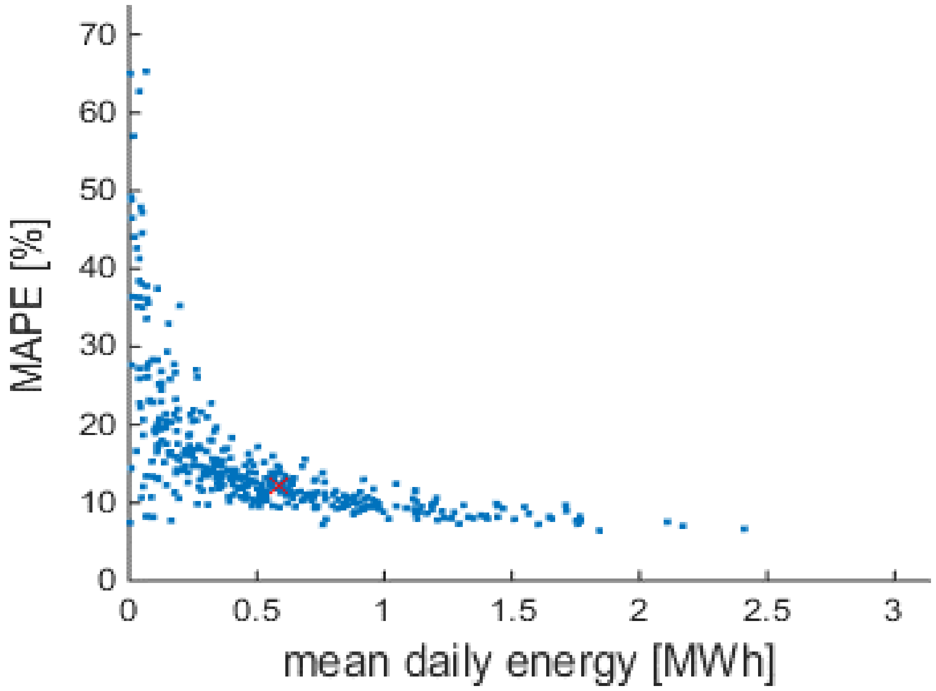
BIG DATA
(> 100 GB)



- Usage of SmartMetering data for grid insights (50’000 SmartMeter)
- Grid transparency via time-series based distribution grid simulation and analysis

Predicting Household Load Profiles (as measured by Smart Meters)





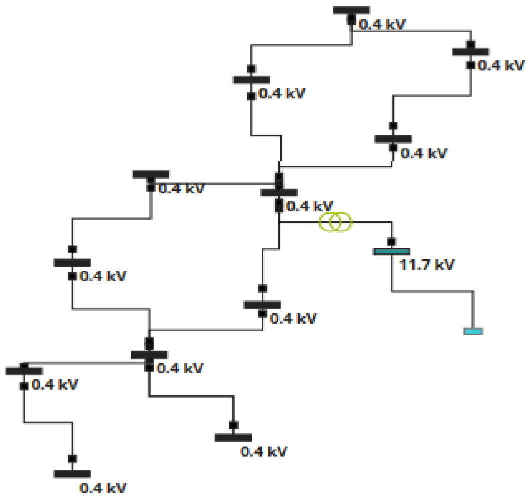
Good prognosis on aggregated level
Good protection of customers' data privacy

T. Zufferey, A. Ulbig, S. Koch, G. Hug, "Forecasting of Smart Meter Time Series Based on Neural Networks", *ECML-PKDD'16*, Riva del Garda (Italy), 19-23 September 2016

Smart Meter-based Distribution Grid Monitoring (Prototype in 2016)

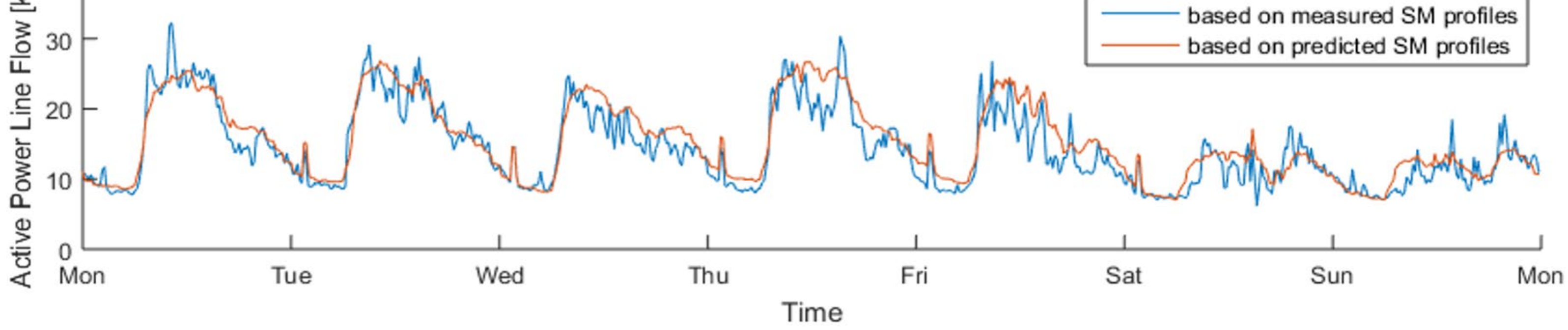
Use-Case: Smartmeter-based Monitoring

Test grid area with 200 end-consumers

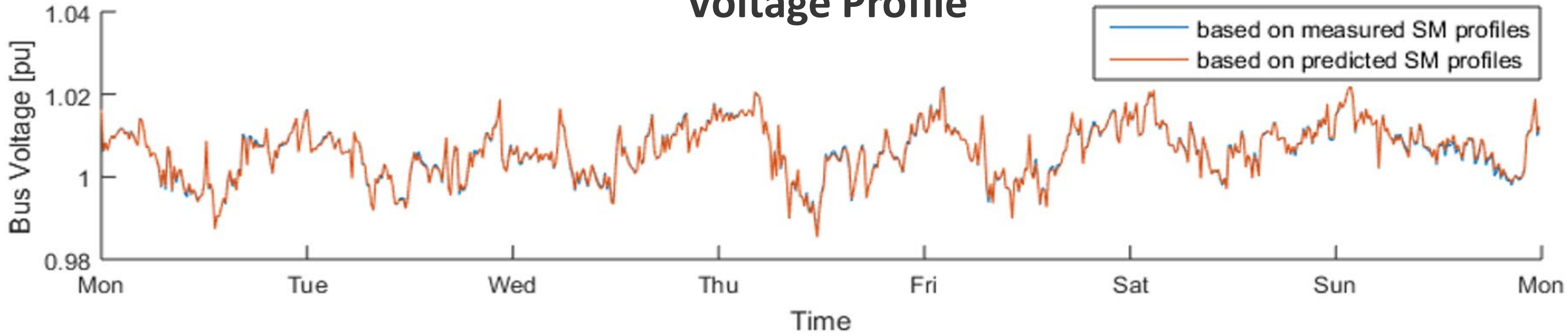


Power Systems Laboratory

Power Flow



Voltage Profile



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Smart Meter-based Distribution Grid Monitoring (Commercial Solution by 2021)

Goals for Distribution Grid Operation

- Monitoring of LV and MV grid level based on Smart Meter and LV transformer measurements with continuous (=daily) data updates
- **Grid data usage allowed & desired by Swiss energy law** (StromVV Art. 8d)
- Beyond monitoring – creation of realistic data basis for grid planning

EW HÖFE

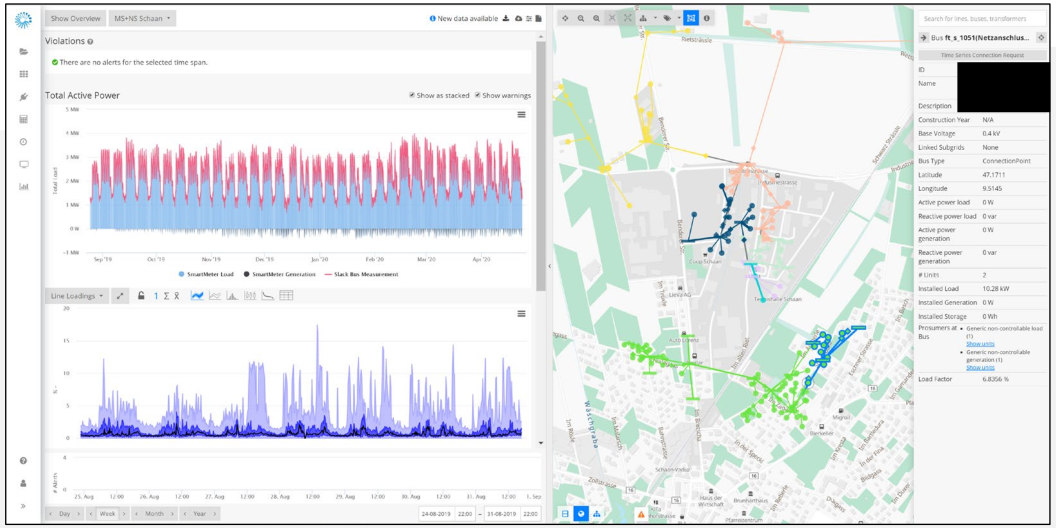
LKW unsere energie

TECHNISCHE BETRIEBE WIL STROM GAS WASSER KOMMUNIKATION

Monitoring Rollouts in Switzerland

ENERGIE INSTALLATION NETZE EWJR

technische betriebe glarusnord



Smart Meter-based Distribution Grid Monitoring

Daily Check of Distribution Grid Operation

GEWINNER DES watt d'or 2021

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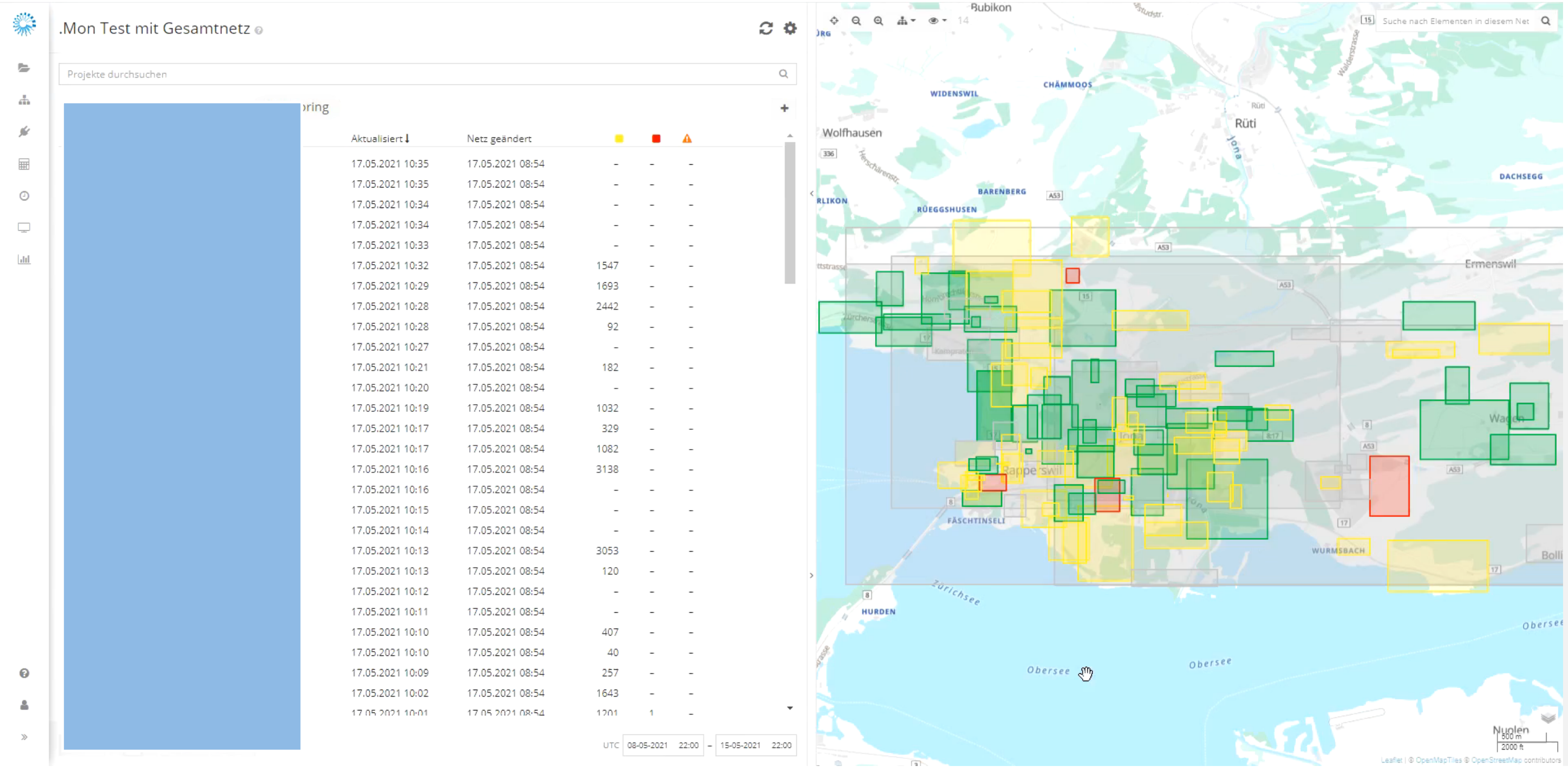
ENERGIE INSTALLATION NETZE EWJR



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Measurement Data-driven Grid Planning and Analysis

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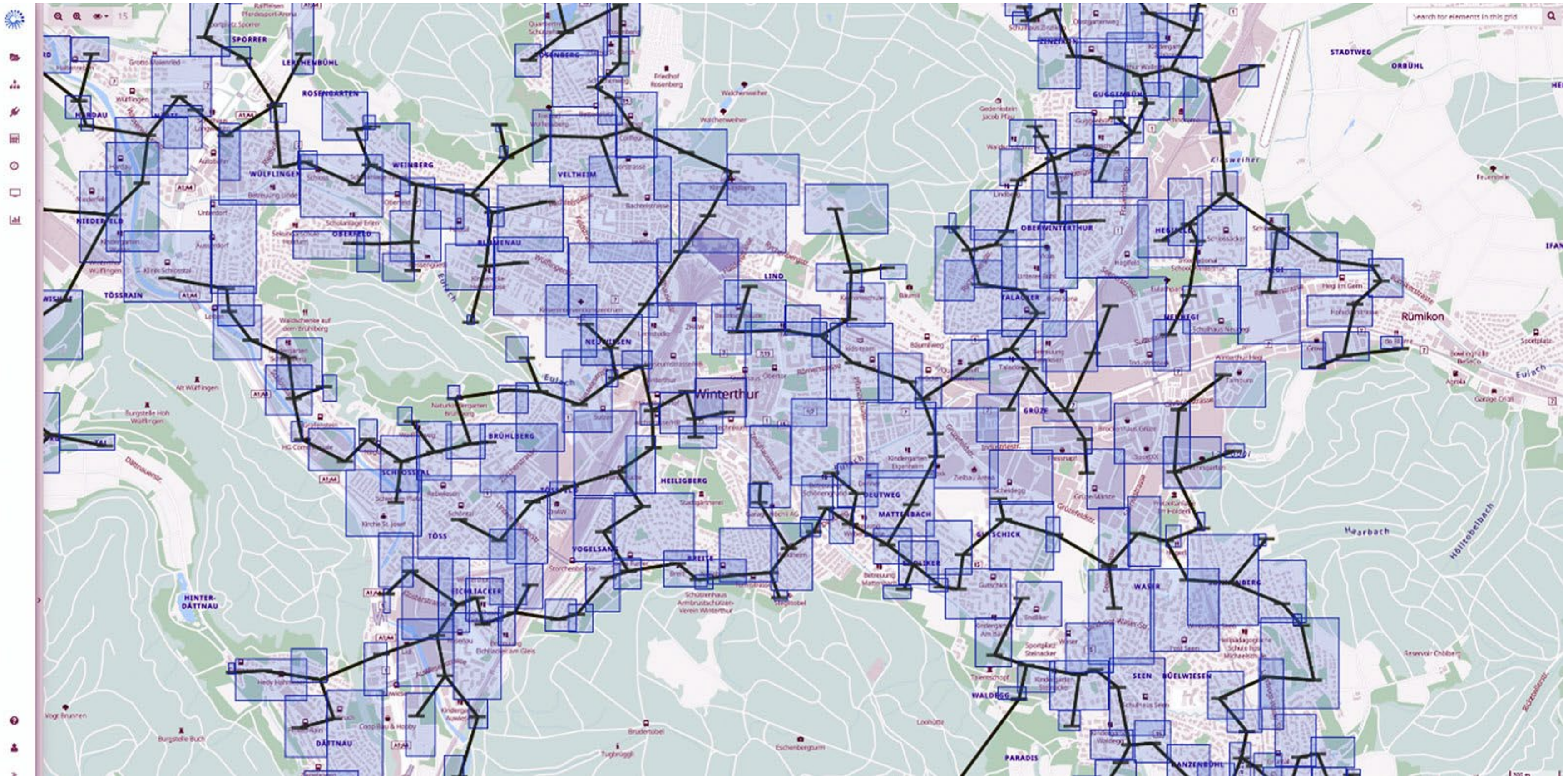
Use-Case: Data-driven Grid Planning

STADTWERK WINTERTHUR

Key Facts

- City of Winterthur with ~100’000 inhabitants
- **Grid Area**
  - 5 HV/MV substations
  - 350 LV transformer (2/3 with sensors)
- **Data Integration**
  - SmartMeter data
  - Industrial and commercial customers
  - PV, BHKW, …
  - Trafo sensors
  - GIS database
- **Goal**
  - **Data-driven grid planning in daily operation**

Grid Area of City of Winterthur (slightly anonymized)



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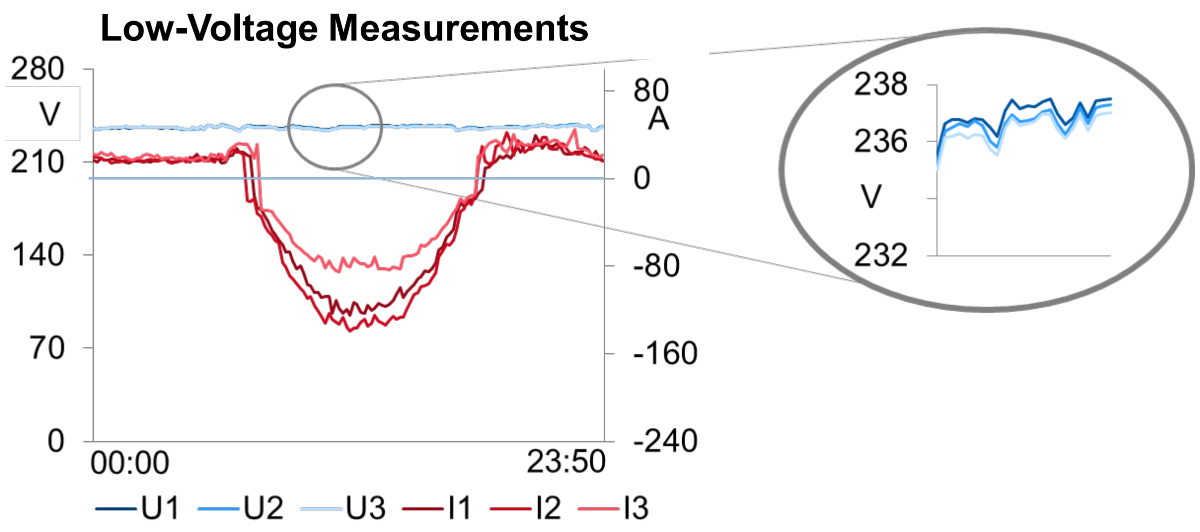
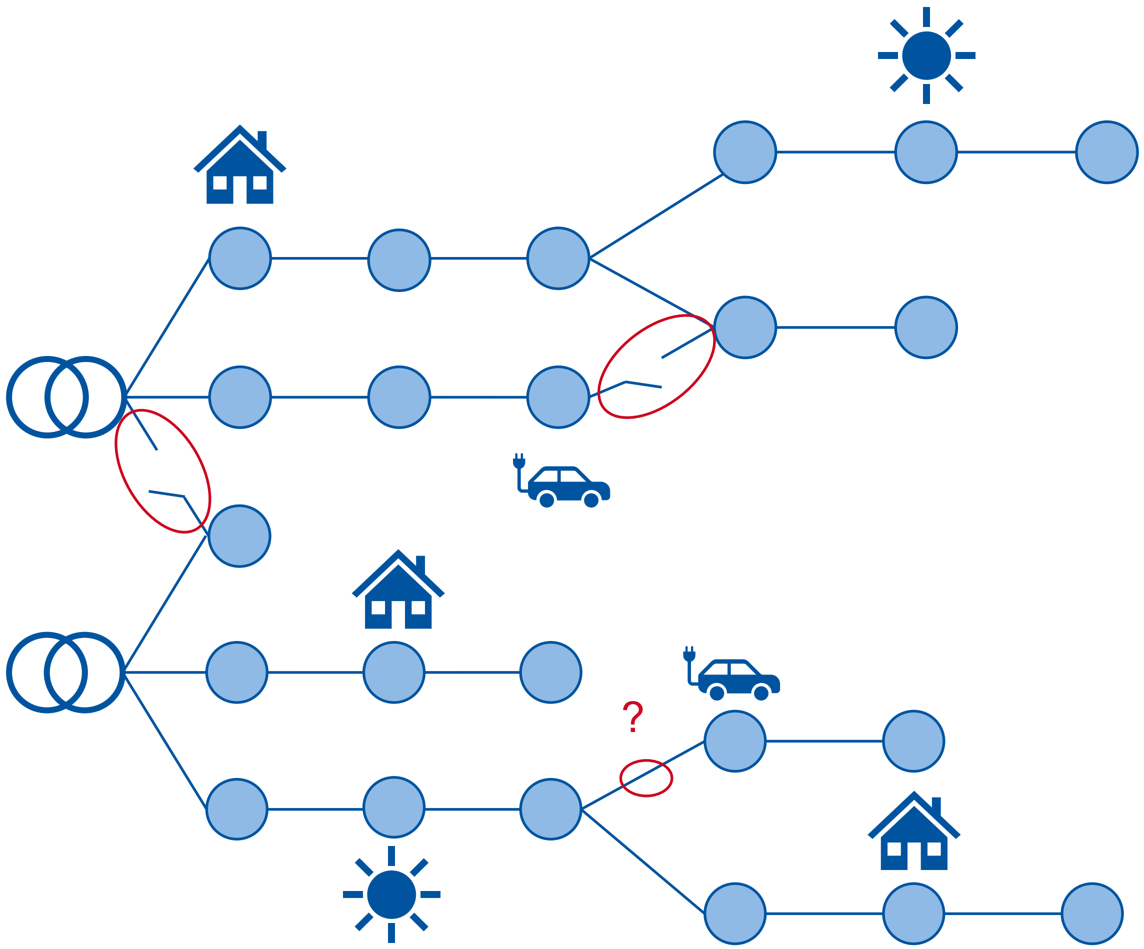
Degrees-of-Freedom in Distribution Grid Topologies

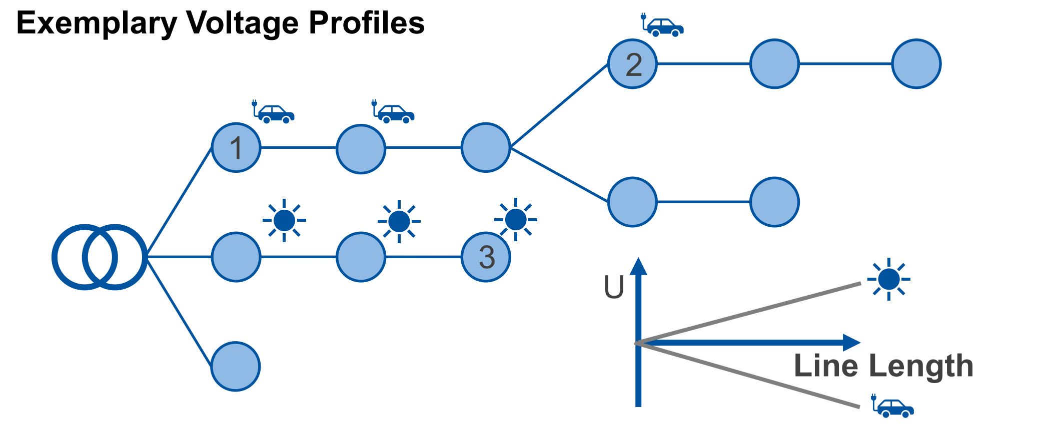
- Electric paths between grid connection points
- Switching states within electrical switch panel
- Switching states within cable distribution cabinet
- Line impedance and, implicitly, line type / material



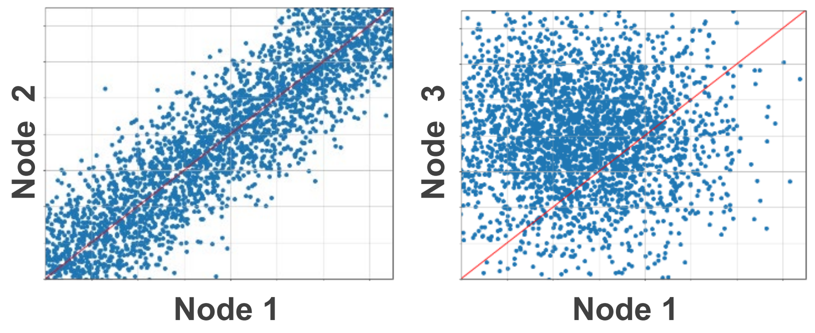


Digitalization in Distribution Grids – Grid Topology Identification and Validation

Exemplary Voltage Profiles

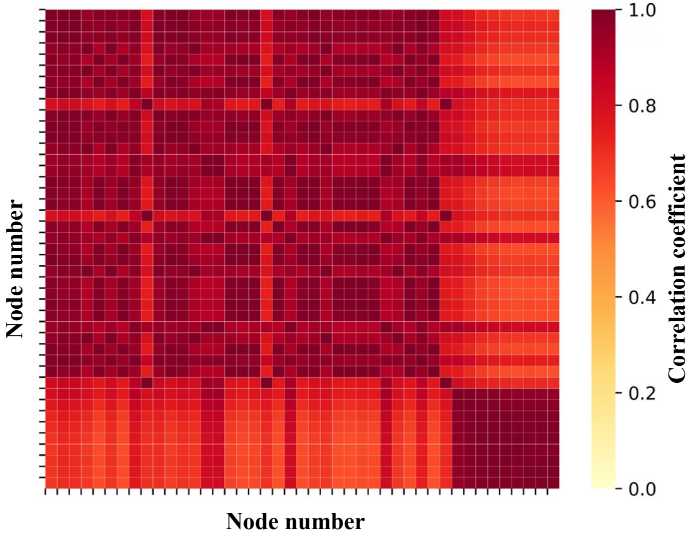


Correlation Analysis – LV Voltage Measurements



Evaluation of Correlation Coefficients (Ex. Pearson)

- $$\rho(x,y) = \frac{\frac{1}{N}\cdot\sum_{n=1}^{N}(x_n-\bar{x})\cdot(y_n-\bar{y})}{\sqrt{\frac{1}{N}\cdot\sum_{n=1}^{N}(x_n-\bar{x})^2}\cdot\sqrt{\frac{1}{N}\cdot\sum_{n=1}^{N}(y_n-\bar{y})^2}}$$

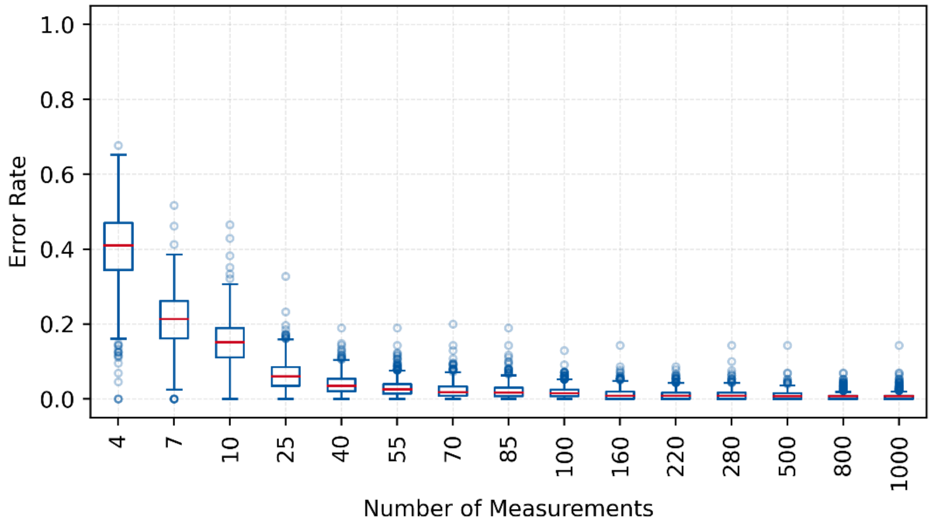


Influence of the number of measurement steps

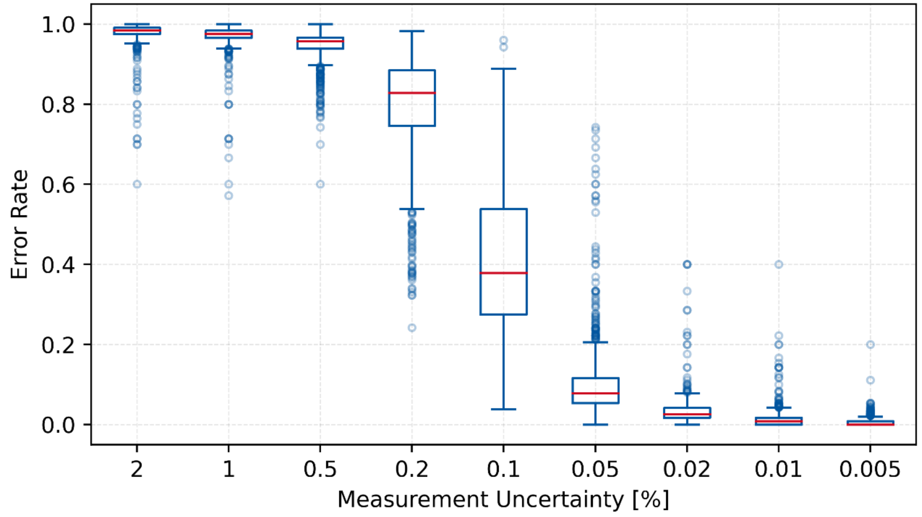
- Variation in the number of non-consecutive measurement time-steps
- Convergence from approx. 100 measurement time-steps → Corresponds to approx. **1 day at 15 min. resolution**

Influence of statistical measurement uncertainty

- Variation of the statistical measurement uncertainty of the measured voltage values
- With 1% measurement uncertainty (current status quo), grid topology identification is **not possible in practice**...



Error rate of topology detection as a function of the number of measurement data



Error rate of topology detection as a function of the statistical measurement uncertainty

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RWTH‘s Distribution Grid Lab

Purpose

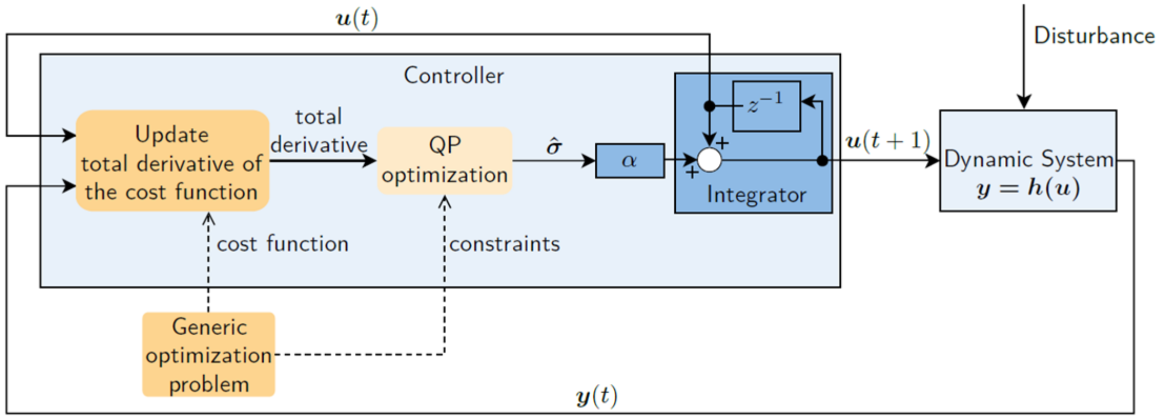
- **Setup of benchmark MV/LV grids**, incl. inverter-connected components, prosumer setups
- **Testing and evaluating grid hardware**, both primary and secondary components, as well as grid operation concepts under *real / realistic operation conditions*
- Microgrid operation both *grid-connected* as well as *off-grid* possible

Available Laboratory Infrastructure

- 4 MW connection capacity, 2 km MV cable, 4 km LV cable, MV/LV transformer stations
- Several load banks (20 kW up to 1MW), BESS (100kW), inverters, generator
- **Full ICT infrastructure (control room…)**

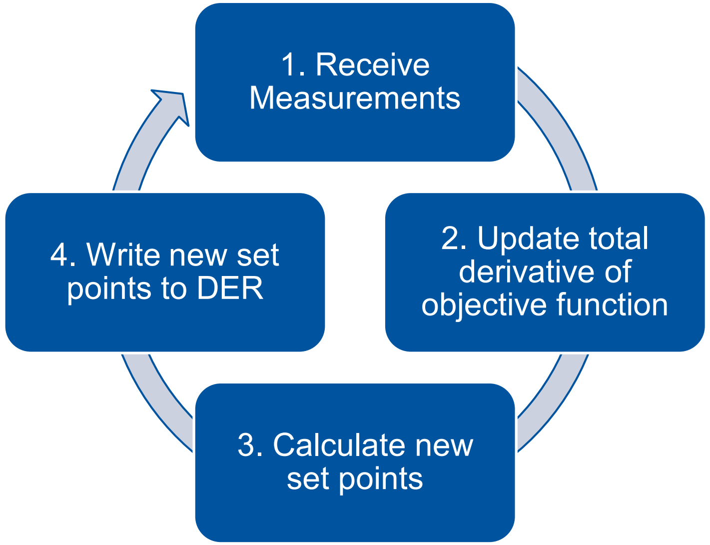
RWTH‘s Distribution Grid Lab

Use Case: Flexibility coordination via Online Feedback Optimization (OFO) cf. Florian Dörfler et al (ETH Zurich)



Concept

- Optimization algorithm in closed-loop with the physical power grid
- Iteratively receiving measurements from the system and sending set points to controllable DER
- Convergence over several iterations to the optimum of the generic optimization problem (e.g. dispatch problem)
- Robust against inaccurate model & disturbances due to current measured values
- No complete model necessary due to measured values from the physical system

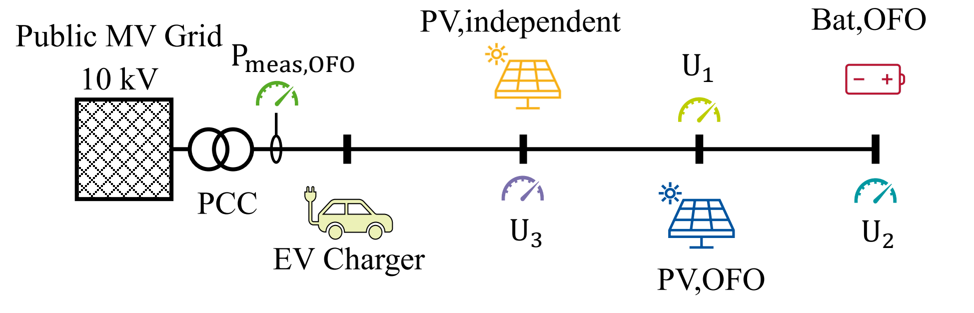


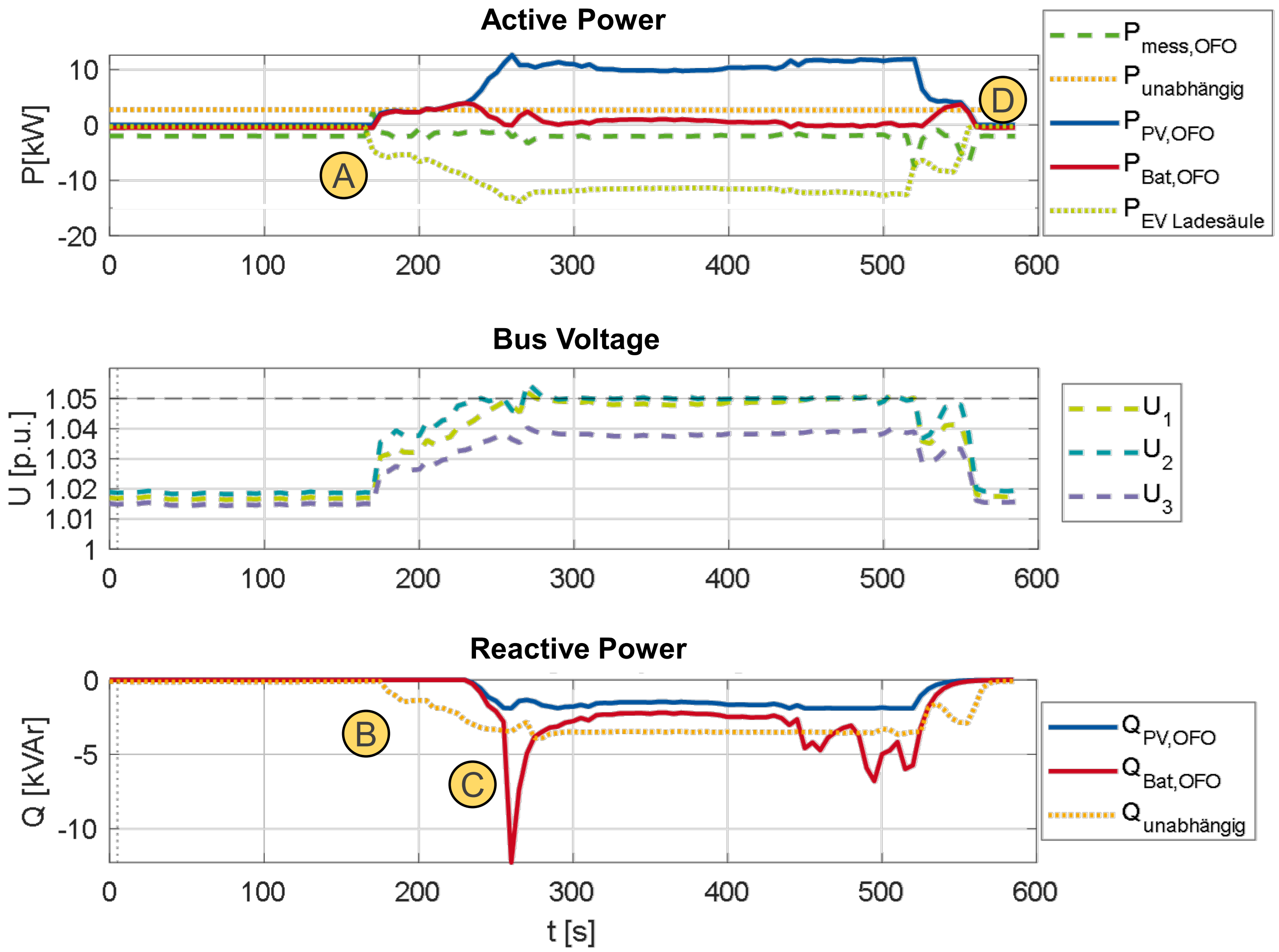
Use Case: Flexibility coordination for congestion management in superimposed grid layers

RWTH‘s Distribution Grid Lab

Experiment: EV charging (OFO-controlled)

- Set point for active power at PCC with $P_{meas} = -2kW$
- EV starts charging process at 170s (A)
- Implicit measurement of disturbance due to distributed measurements in the LV feeder
- Start of volt/var control (B)
  - Independent PV inverter with Q(V)-control: 1.03 p.u.
  - OFO voltage constraint: 1.05 p.u. (C)
- OFO is able to ensure set point tracking despite of disturbance due to EV charging (D)





Conclusions and Key Messages for Digitization in Distribution Grids

- Distribution grid will be at the core of RES integration and the energy transition (e.g. electrification)
  - ► **Technical challenges can always be tackled via "hard paths" or "soft paths" (Amory Lovins)**
  - ► **»More copper« is technically feasible but economically prohibitive (cost explosion)**
- Digitization not trival … historically, *was* either technically not feasible or economically not meaningful
  - ► **Rapid cost decreases in ICT allow new solutions**
  - ► **»More intelligence« is becoming cheaper and better than «more copper»**
- Digitization *can* lead to more cost efficiency in distribution grids
  - ► **1) Collect data, 2) Analyse data, 3) Apply data-driven analytics** for improving investment decisions
  - ► Take advantage of mandatory smart meter rollout (collect more KPIs, e.g. voltage, power quality)
  - ► Install additional sensors at neuralgic locations (secondary substations, distribution cabins)
- Innovation *needs* motivation (= technical challenges and fitting regulatory framework)
  - ► **From regulatory perspective, the *smart choice* is in many jurisdictions still the *dumb cable*** ☹

Digitalization of distribution grids – an incremental path