Research Project SiNED Insights – Ancillary Services for Reliable Power Grids in Times of the Progressive German Energiewende and Digital Transformation

ETG-Kongress 2023

Structure

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- **1.1 Contributions to overall system stabilization in the transmission grid through coordinated ancillary service provision at the distribution grid level**
- **1.2 Demand analysis, control engineering, and concepts for ancillary services for the compensation of fast load jumps in distribution networks**
- **1.3 Ancillary services of the grid-serving prosumer with storage, photovoltaics, electromobility and heat pump**
- **1.4 Protection systems in networks with distributed converters**

2 Digital Transformation / Information and Communication Technology

- **2.1 Information technology platforms and services for the provision of decentralized ancillary services**
- **2.2 Data, transaction and service concepts for forecasting, deployment planning and marketing of automated and autonomous activation of decentralized ancillary services**
- **2.3 AI tools and frameworks for power flow forecasting and attack vectors on ICT infrastructures**

3 Energy Law and Economics

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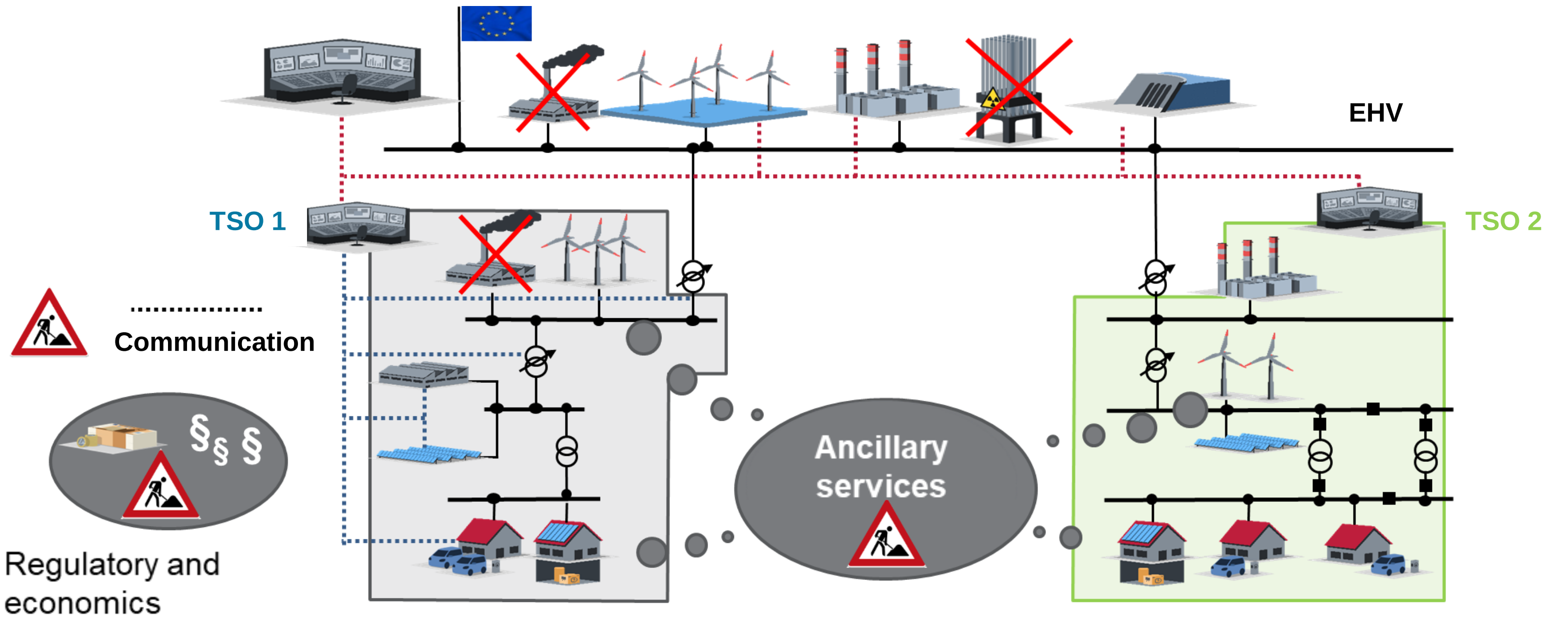
- **3.2 Legal framework for ancillary services**

Conclusion and Outlook

Introduction and Motivation

Introduction and Motivation

- How can the changing demand for ancillary services (ASs), which increasingly have to be provided by decentralized distributed energy resources (DERs), be met in the future until 2045?
- How can the demand for ASs be met by the flexibility of prosumers, and how can this challenge be solved by converter-dominated distribution grids?
- How can flexibility for providing ASs in distribution grids be developed in terms of information technology, taking resilience into account?
- Which economic optimization potentials are possible for the provision of ASs, which (data protection) legal restrictions have to be considered, and which adjustments of the regulatory frameworks are necessary?



1 Electrical Power Engineering

Topics

- **1.1 Contributions to overall system stabilization in the transmission grid through coordinated ancillary service provision at the distribution grid level**
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- **1.3 Ancillary services of the grid-serving prosumer with storage, photovoltaics, electromobility and heat pump**
- **1.4 Protection systems in networks with distributed converters**

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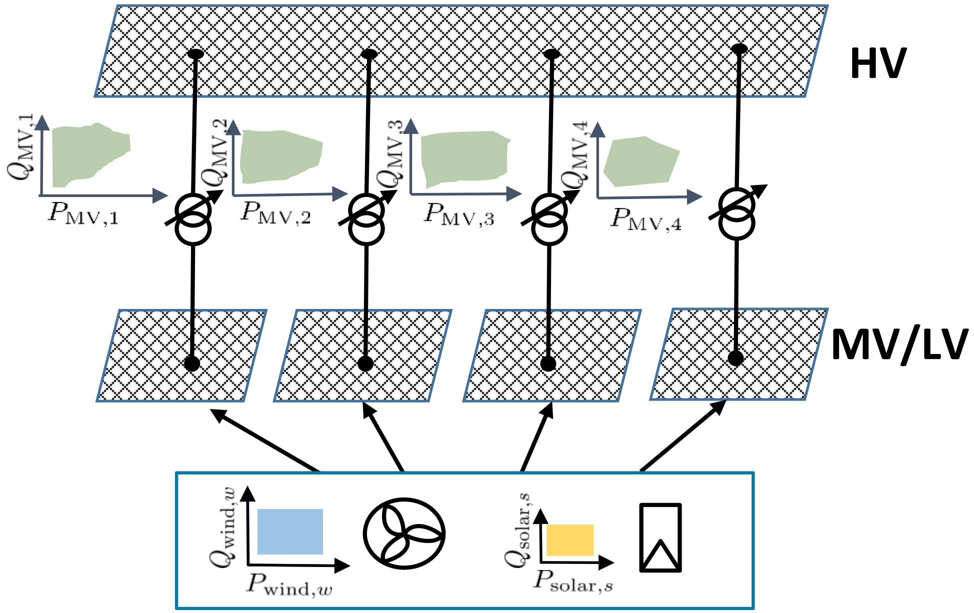
Leibniz Universität Hannover
ifes – Institut für Hochspannungstechnik und Energiesysteme
Carl von Ossietzky Universität Oldenburg
DLR Institut für Vernetzte Energiesysteme
OFFIS Institut für Informatik
TU Clausthal – Clausthal University of Technology

1.1 – Contributions to overall system stabilization in the transmission grid through coordinated ancillary service provision at the distribution grid level

Neelotpal Majumdar, Dr.-Ing. Thomas Leveringhaus, Prof. Dr.-Ing. Lutz Hofmann

Vertical active and reactive power flexibility provision as basis for TSO-DSO Coordination

- Aggregated active and reactive power (PQ) flexibility determined at the HV/MV interconnection from distributed energy resources (DER)
- Aggregated PQ- flexibility as an interface for TSO-DSO coordination, to enable efficient utilization of flexibilities at the overlaying grids
- For DERs at the combined MV/LV grid level, simplified rectangular PQ capability curves assumed as demonstrated
- MV/LV grids on which the methods are applied are a modified version of the Benchmark Cigrè MV grid
- The aggregated flexibility is also termed in literature as Feasible Operating Region (FOR)
  - Posed as an optimization problem adhering to the technical grid and technology constraints of the MV/LV grid level
  - Solved by linear optimization which provides fast results with negligible loss of quality



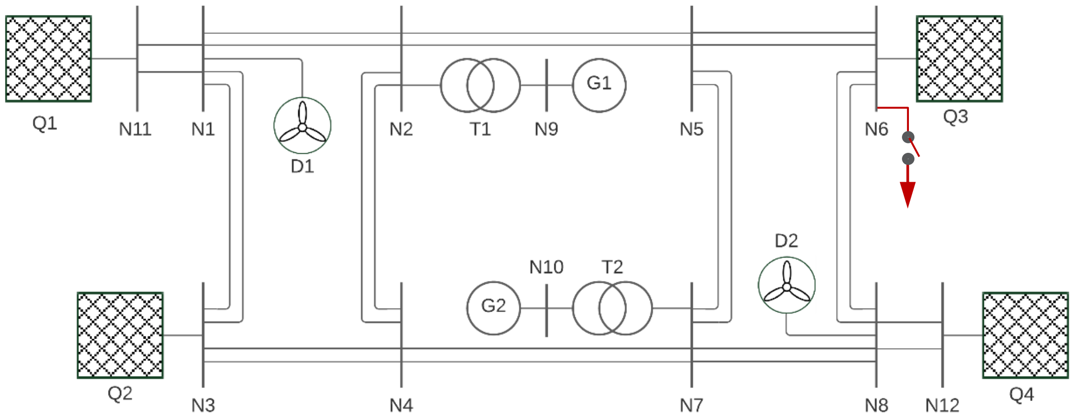
DER PQ-capabilities in MV/LV grid levels

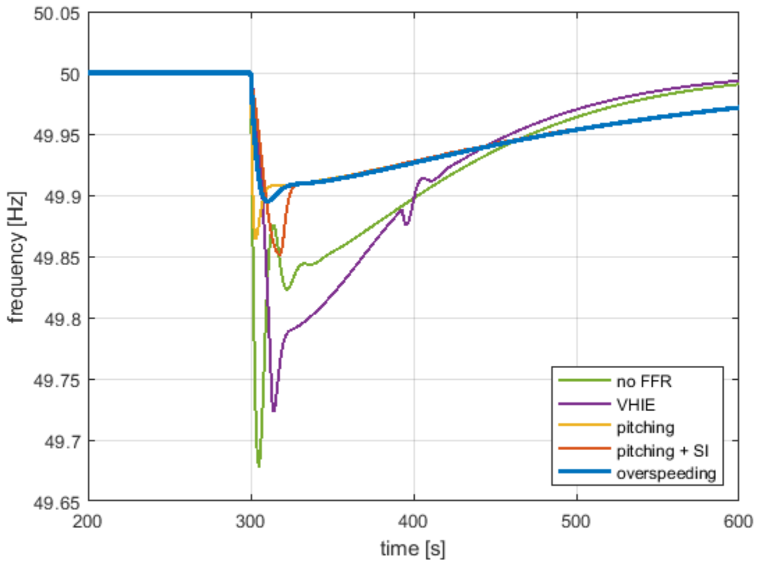
Fast frequency response strategies through decentralised renewable generation

- Fast frequency response (FFR) are investigated on a 12 node benchmark grid as demonstrated

- Different strategies investigated are classified as:
  - With 10% reserve power (curtailed generation)
    - Pitching
    - Overspeeding
  - Without reserve power (generation uncurtailed)
    - Virtual Hidden Inertia Emulation (VHIE) or Synthetic Inertia (SI)
  - Combined approach
    - Pitch control combined with SI

- **Due to higher levels of reserved active power flexibility, pitch control and overspeeding provide improved FFR**
  - Increased economic losses due to curtailed generation

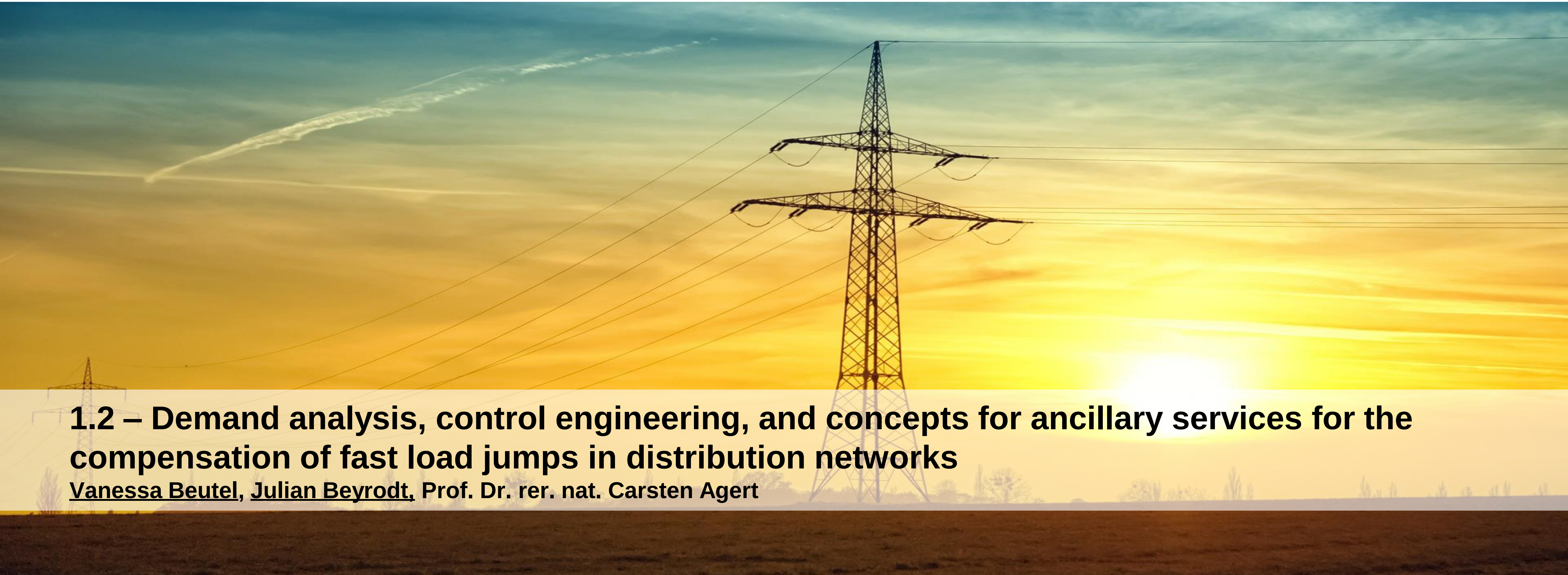




Prof. Dr.-Ing. Lutz Hofmann
hofmann@ifes.uni-hannover.de
Tel.: 0511 762-2801
- **Projektleitung**

Dr.-Ing. Thomas Leveringhaus
leveringhaus@ifes.uni-hannover.de
Tel.: 0531 391-4426
- **Projektleitung**

Neelotpal Majumdar, M.Sc.
majumdar@ifes.uni-hannover.de
Tel.: 0511 762-19985
- **Projektbearbeitung**



1.2 – Demand analysis, control engineering, and concepts for ancillary services for the compensation of fast load jumps in distribution networks

Vanessa Beutel, Julian Beyrodt, Prof. Dr. rer. nat. Carsten Agert

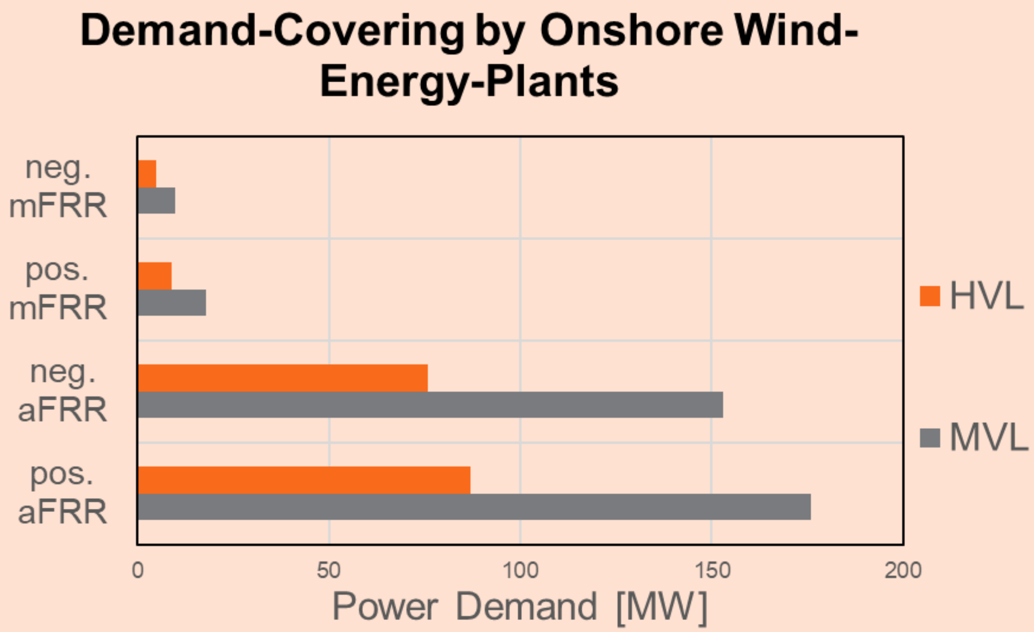
Demand analysis and control algorithms for converter-based grids

Demand analysis and control power algorithm for frequency stability

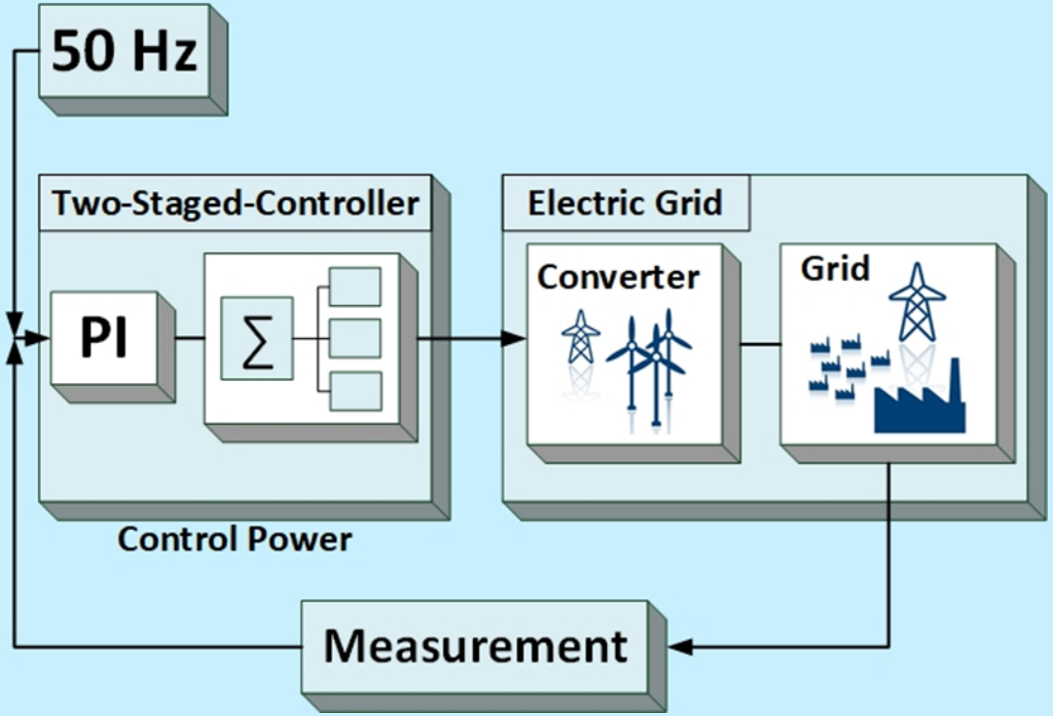
Goal:

Development of a grid-controller for systems with converter-based power supply and reduced inertia

- Demand analysis



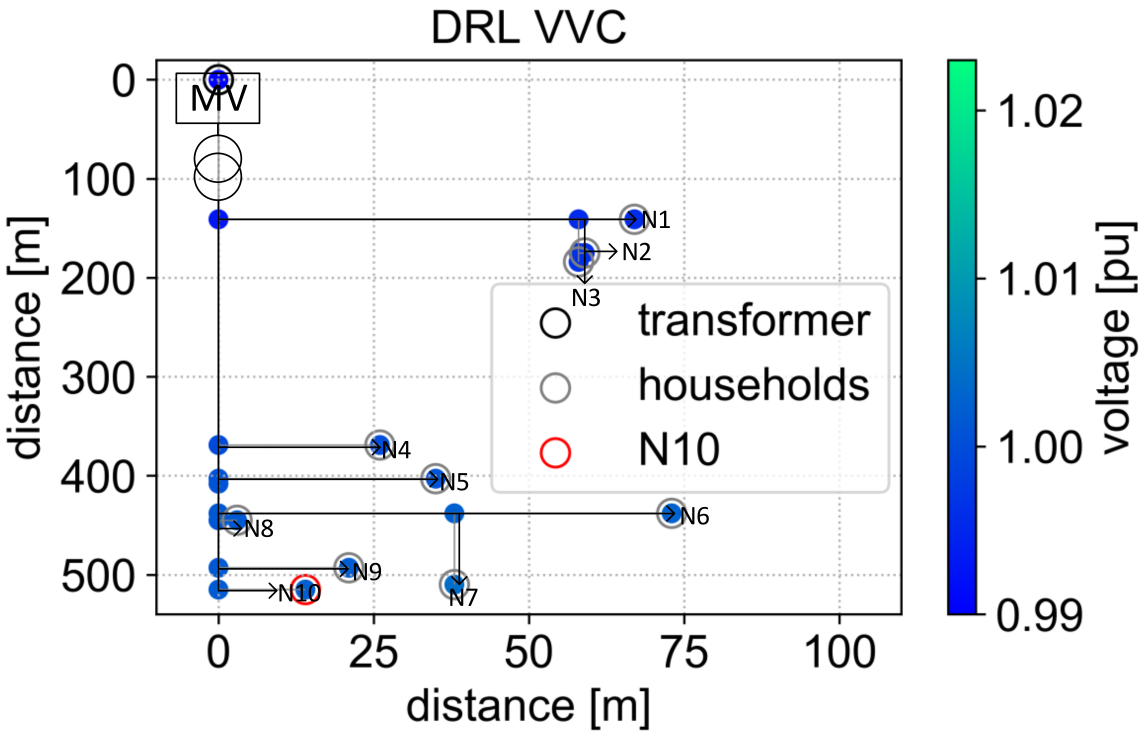
- Frequency stability



Demand analysis and control algorithms for converter-based grids

Machine-Learning algorithm for voltage-stability with reactive power control

- **Machine-Learning algorithm for reactive power control**



- **Reactive power stabilize the voltage**

- **Hardware-based Validation in grid environment**

Ancillary services of the grid-serving prosumer household

Contact Details

- Julian Beyrodt M.Eng.
- Phone: + 49 4419 9906 135
- Mail: Julian.Beyrodt@dlr.de

DLR Institute of Networked Energy Systems

Deutsches Zentrum für Luft- und Raumfahrt
Institut für Vernetzte Energiesysteme
Prof. Dr. rer. nat. Carsten Agert

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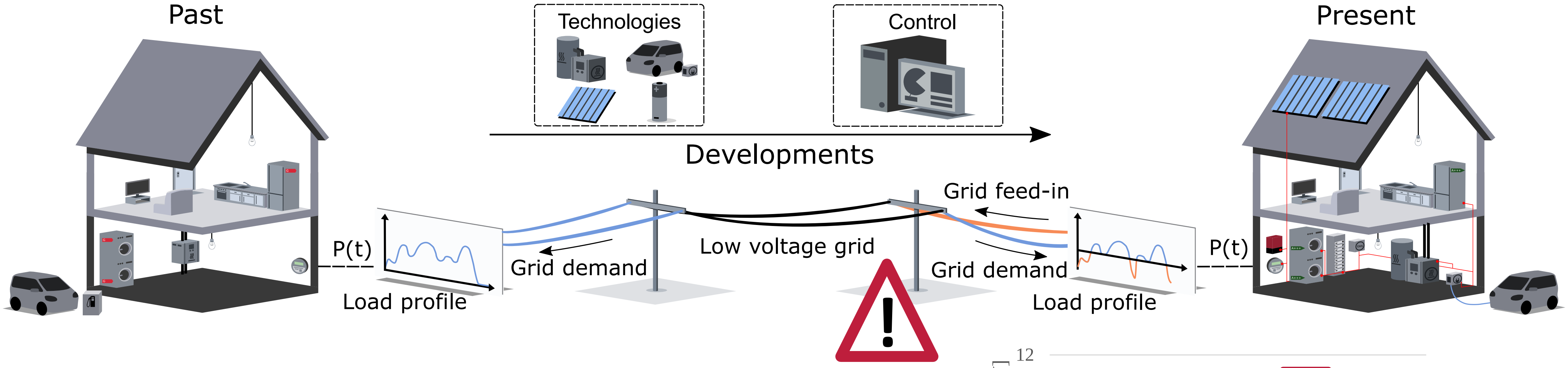
1.3 – Ancillary services of the grid-serving prosumer with storage, photovoltaics, electromobility and heat pump

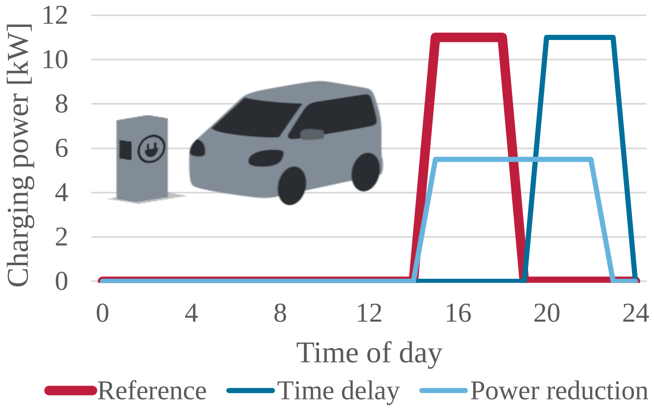
Carsten Wegkamp, Prof. Dr.-Ing. Bernd Engel

Prosumer with storage, PV, electromobility, and heat pump

- High impact of comparatively large prosumer devices on **critical grid situations** in the LV grid



- Offer high degree of **flexibility**, e. g. by shifting charging processes



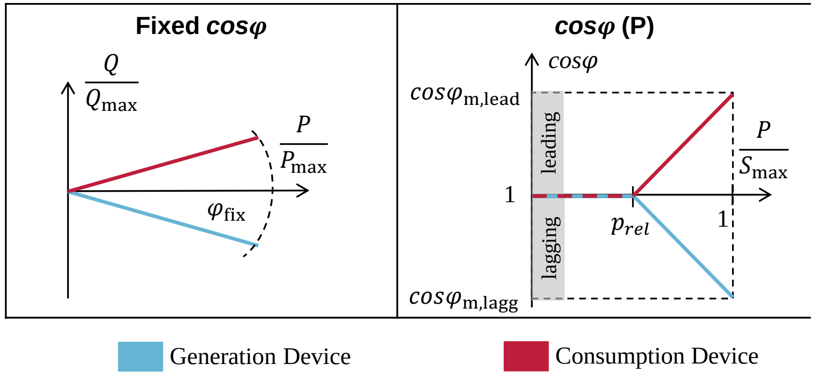
Flexibility of electric vehicles

➢ Possibility of providing ancillary services without negative impact of primary use, e. g. mobility

Ancillary services of the grid-serving prosumer: two approaches

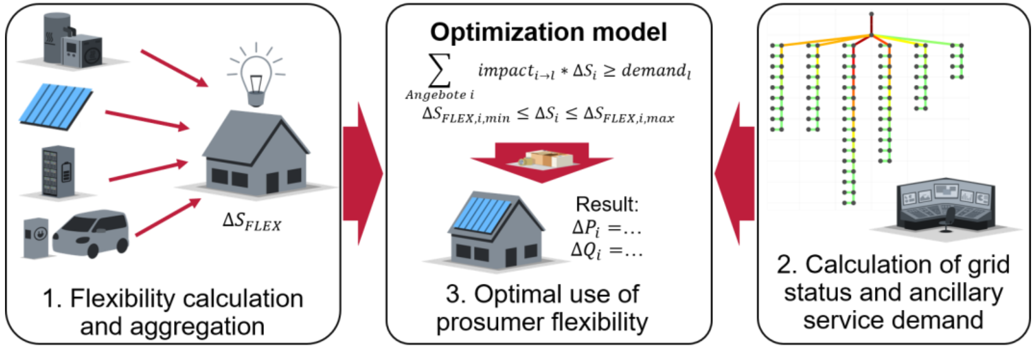
Decentral concepts

- Prescription for **boundary ranges** (e. g. for active power provision) or specific reactional behavior in the form of **characteristic curves** (e. g. for voltage control concepts)
- **Voltage control concepts** for prosumer devices:
  - Different extent of positive impact on voltage control
  - Different effects on prosumer key figures
  - **Prescribed concepts typically aren't optimal** for LV grids



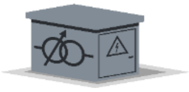
Centrally coordinated AS model

- Efficient covering of AS demand with flexibility from prosumer devices using **sensitivity factors** to quantify the impact



- **Grid status and impact of power adaption is considered**
- Potential to completely eliminate violations for the LV grid

- Future work:
  – provision of frequency control as a global AS
  – technical synergies of multi-used BSS
  – comparison of innovative grid components and grid expansion



Ancillary services of the grid-serving prosumer household

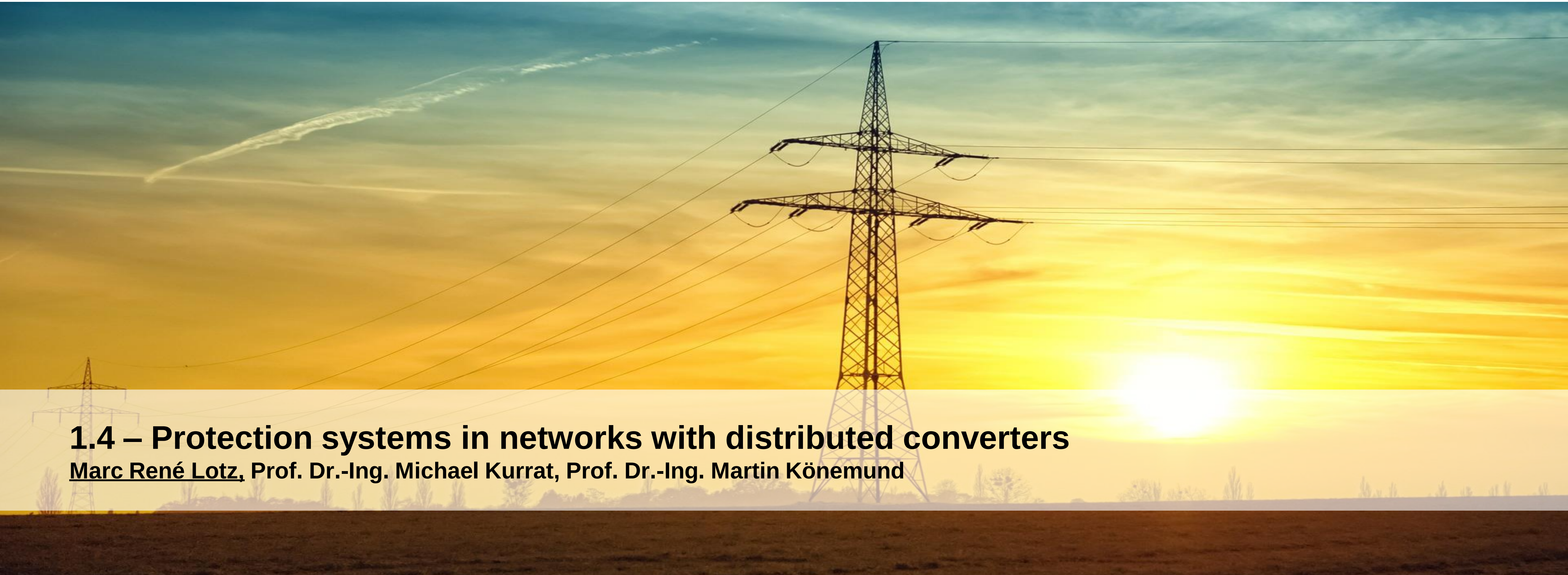
Contact Details

Carsten Wegkamp

- Phone: + 49 531 391 7756
- Mail: c.wegkamp@tu-braunschweig.de

Institut für Hochspannungstechnik und Energiesysteme

elenia Institute for High Voltage Technologies and Power Systems
Prof. Dr.-Ing. Bernd Engel

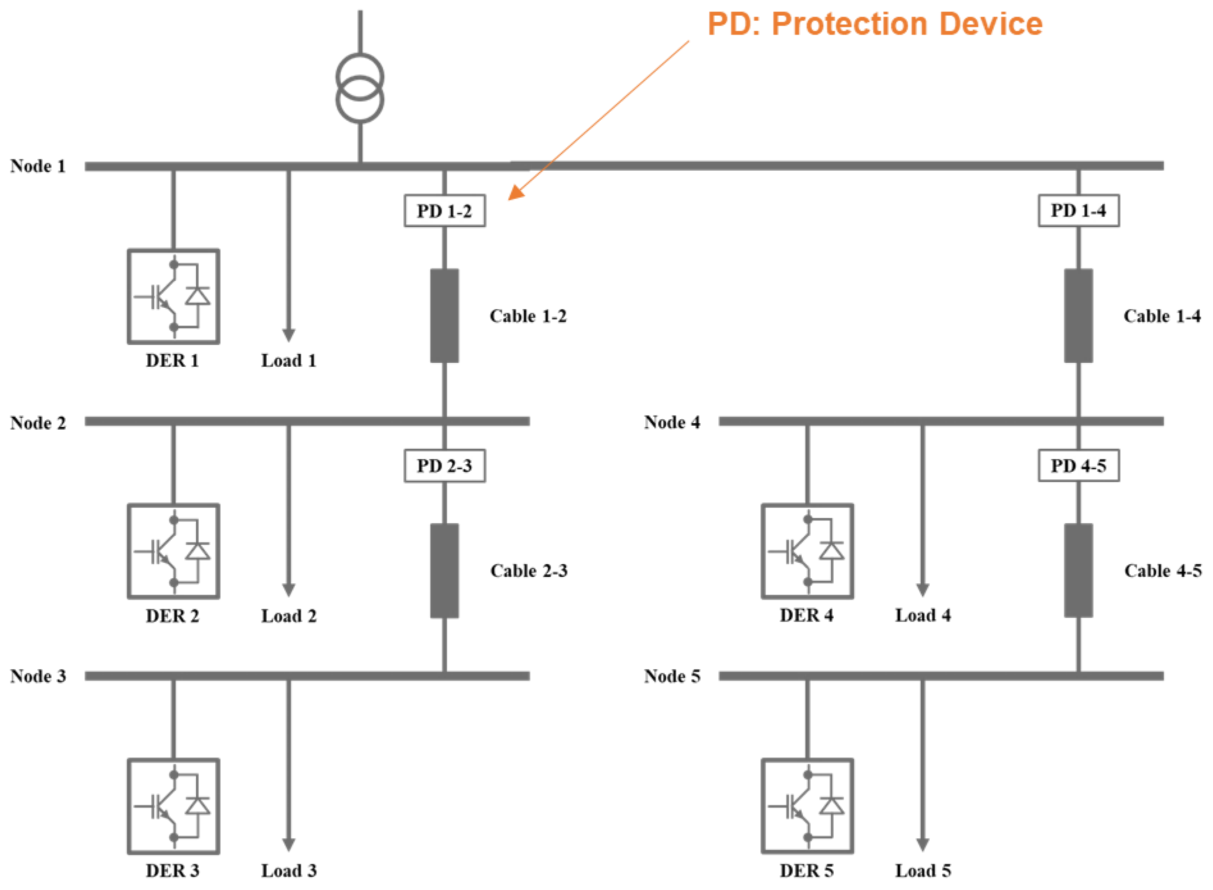


1.4 – Protection systems in networks with distributed converters

Marc René Lotz, Prof. Dr.-Ing. Michael Kurrat, Prof. Dr.-Ing. Martin Könemund

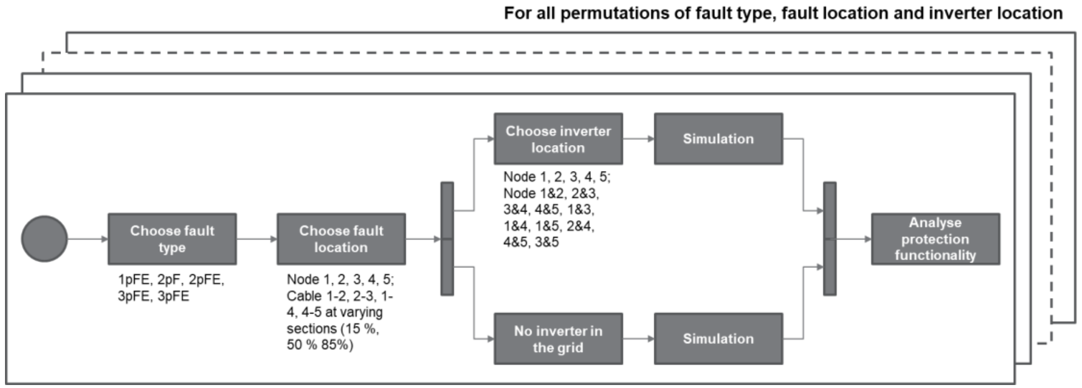
Protection Systems in Distribution Grids

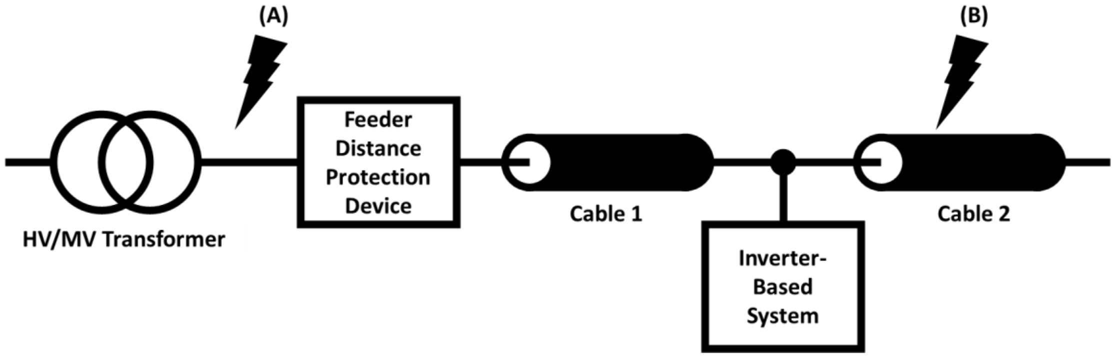
- Ancillary services provided more and more by inverter-based systems
- Reassessment of conventional protection systems essential
  - Increasing variation in power-flow directions
  - Decrease and variability of short-circuit levels
  - Changing topologies and dynamics
- Negative influence on functionality of conventional protection systems
  - Blinding, sympathetic tripping, loss of coordination
- Simulative analysis of influence performed
  - Cigré benchmark system for DER integration
  - Adapted by inverters, controls, and protection systems
  - Compliant with VDE-AR-N 4110 (TCR)
  - Literature findings have been validated



Protection Systems in Distribution Grids

- Various fault scenarios have been analyzed
  - Distance protection system functionality could be negatively influenced
  - Overreach/underreach issues, errors in fault location estimation, loss of backup protection
  - Fault (B) leads to error impedances due to intermediate infeed configuration
- Outlook
  - Proposal and simulative validation of protection concepts
  - Focus on adaption of inverter-based controls (see another VDE ETG Congress contribution)
  - Experimental validation of findings and proposals with laboratory-scale PHiL experiments





Protection Systems in Distribution Grids

Contact Details

Marc-René Lotz

- Collaborative work between TU Braunschweig and Ostfalia
- Research: HVDC, PHiL
- Phone: + 49 5331 939 43 22 0
- Mail: m.lotz@tu-braunschweig.de or m.lotz@ostfalia.de
- Web: https://www.tu-braunschweig.de/elenia/team/wimi/lotz-marc or https://www.ostfalia.de/cms/de/pws/lotz/

elenia Institut für Hochspannungstechnik und Energiesysteme

elenia Institute for High Voltage Technologies and Power Systems
Prof. Dr.-Ing. Michael Kurrat

ifEA

Institute for Electrical Energy and Automation Systems
Prof. Dr.-Ing. Martin Könemund

2 Digital Transformation / Information and Communication Technology

Topics

- **2.1 Information technology platforms and services for the provision of decentralized ancillary services**
- **2.2 Data, transaction and service concepts for forecasting, deployment planning and marketing of automated and autonomous activation of decentralized ancillary services**
- **2.3 AI tools and frameworks for power flow forecasting and attack vectors on ICT infrastructures**

2.1 – Information technology platforms and services for the provision of decentralized ancillary services

Payam Teimourzadeh Baboli, Amin Raeiszadeh, Michael Brand, Prof. Sebastian Lehnhoff

IT platform and services for the provision of decentralized ancillary services

Project Overview and Team Information

Goals

1. Support decentralized provision of ancillary services.
2. Analyze correlations between time series data.
3. Predict joint-reliability of coalitions.
4. Optimize provision of ancillary services.
5. Provide user-friendly interface for customization.
6. Facilitate integration with other systems.
7. Ensure compliance with industry standards.
8. Manage risks associated with ancillary service provision.

Steps

1. Conducted requirement engineering for platform development.
2. Designed platform architecture with modular components.
3. Choose proper technologies to implement the platform.
4. Developed internal algorithms for data analysis and optimization.
5. Tested platform with the use cases.
6. Documented testing results per industry standards.
7. Demonstrated platform's correlation and reliability prediction capabilities.
8. Optimized ancillary service provision with platform.

Prof. S. Lehnhoff

M. Brand

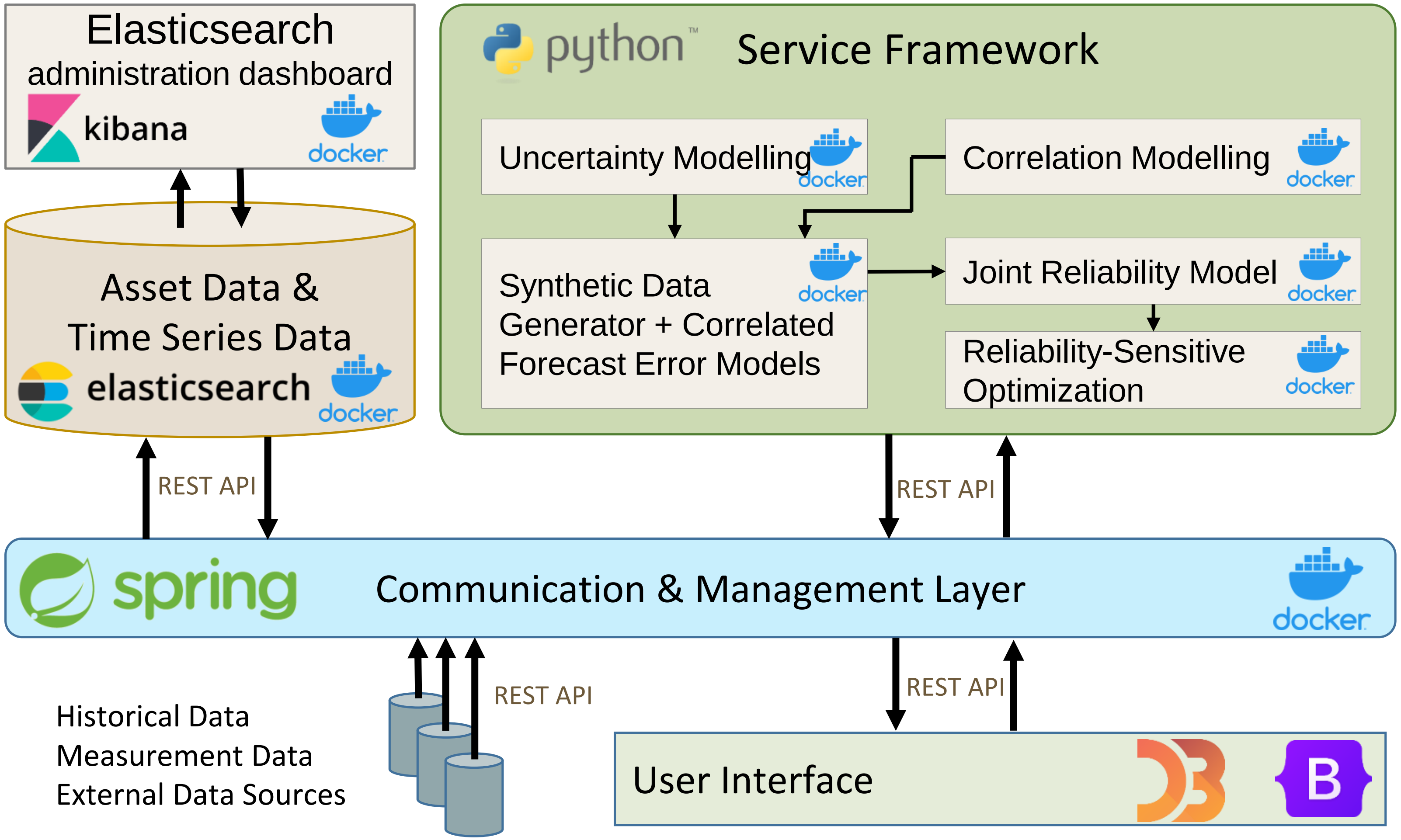
A. Raeiszadeh

P. T. Baboli

IT platform and services for the provision of decentralized ancillary services

The architecture of the proposed service platform

- The proposed service platform has four main modules:
  - Communication & management layer,
  - Database,
  - Algorithms and Service,
  - User interface.
- All modules are dockerized for scalability and flexibility.
- The service platform integrates several algorithms, including data preparation, uncertainty modeling, and correlation graph visualization.
- The platform can generate synthetic data, fit probability distribution functions, compute joint-reliability models, and perform reliability-sensitive optimization.



Contact

Team Information

Prof. S. Lehnhoff

M. Brand

A. Raeiszadeh

P. T. Baboli

Contact:
Payam Teimourzadeh Baboli
Payam.TeimourzadehBaboli@offis.de

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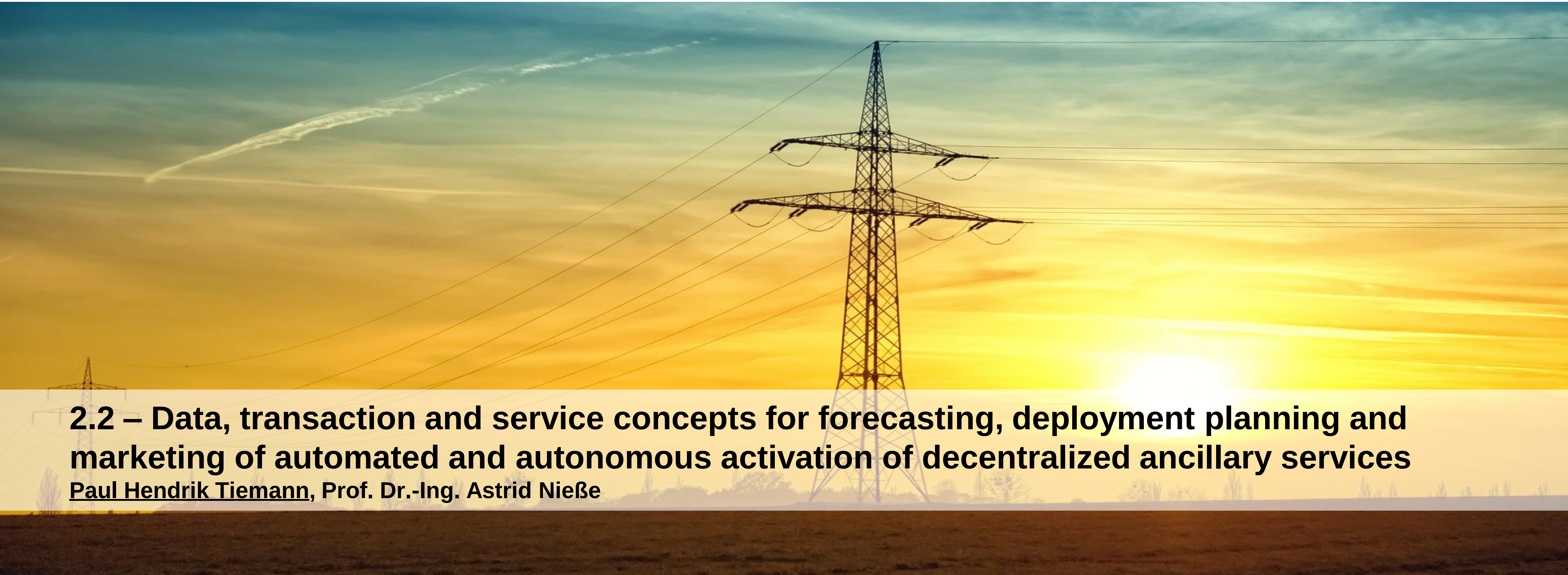
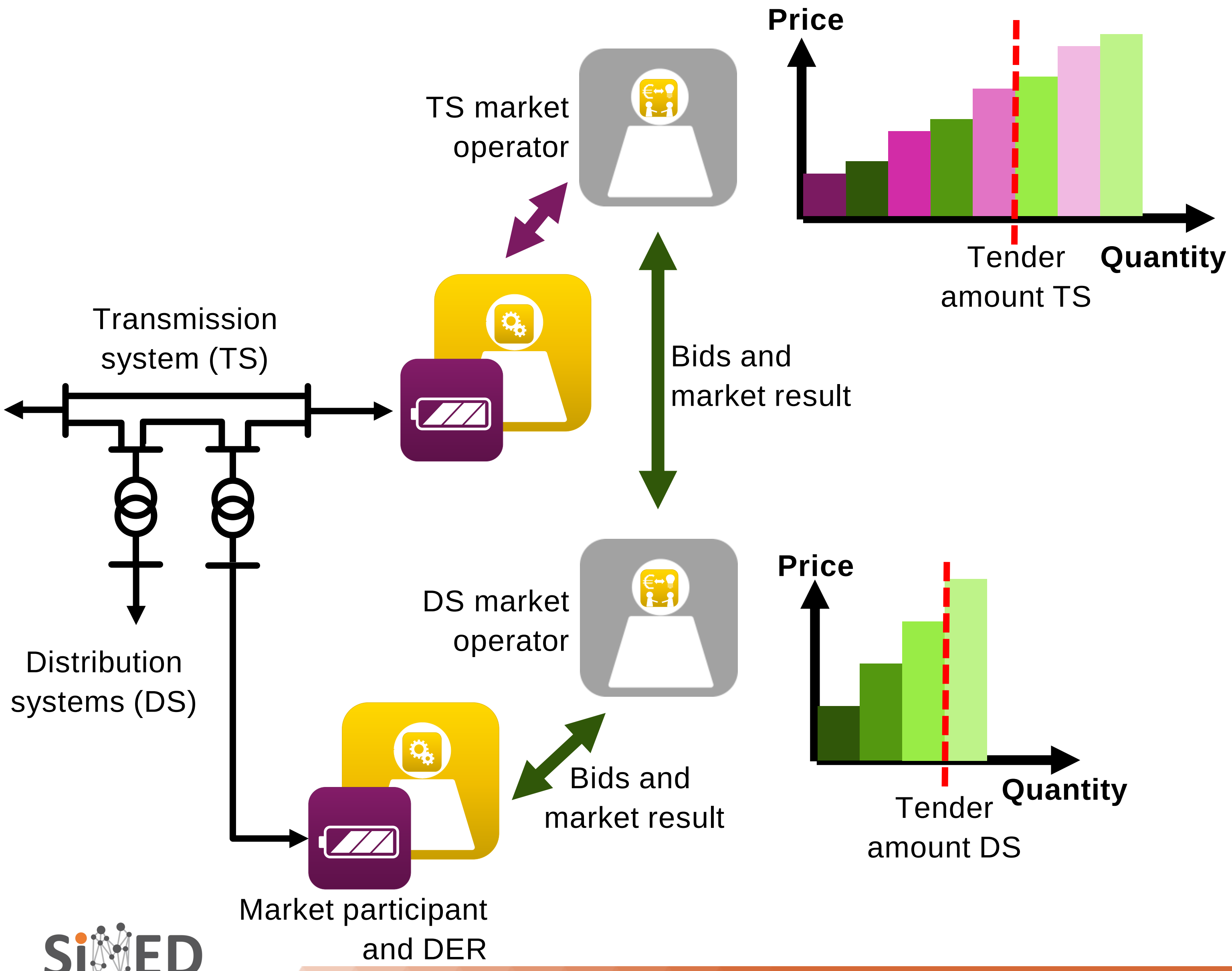


2.2 – Data, transaction and service concepts for forecasting, deployment planning and marketing of automated and autonomous activation of decentralized ancillary services

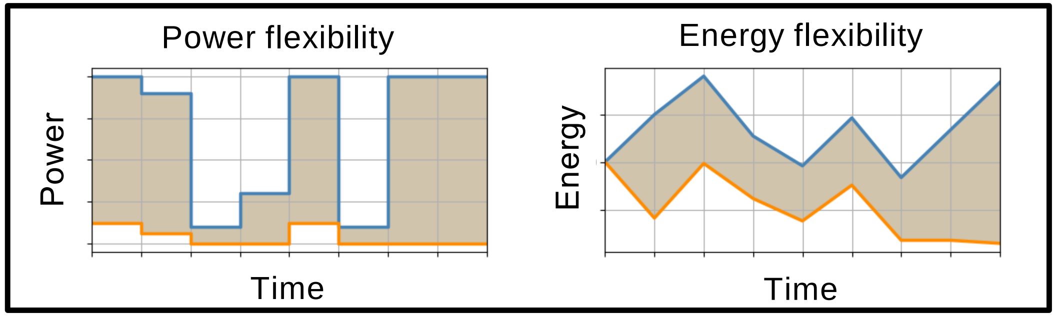
Paul Hendrik Tiemann, Prof. Dr.-Ing. Astrid Nieße

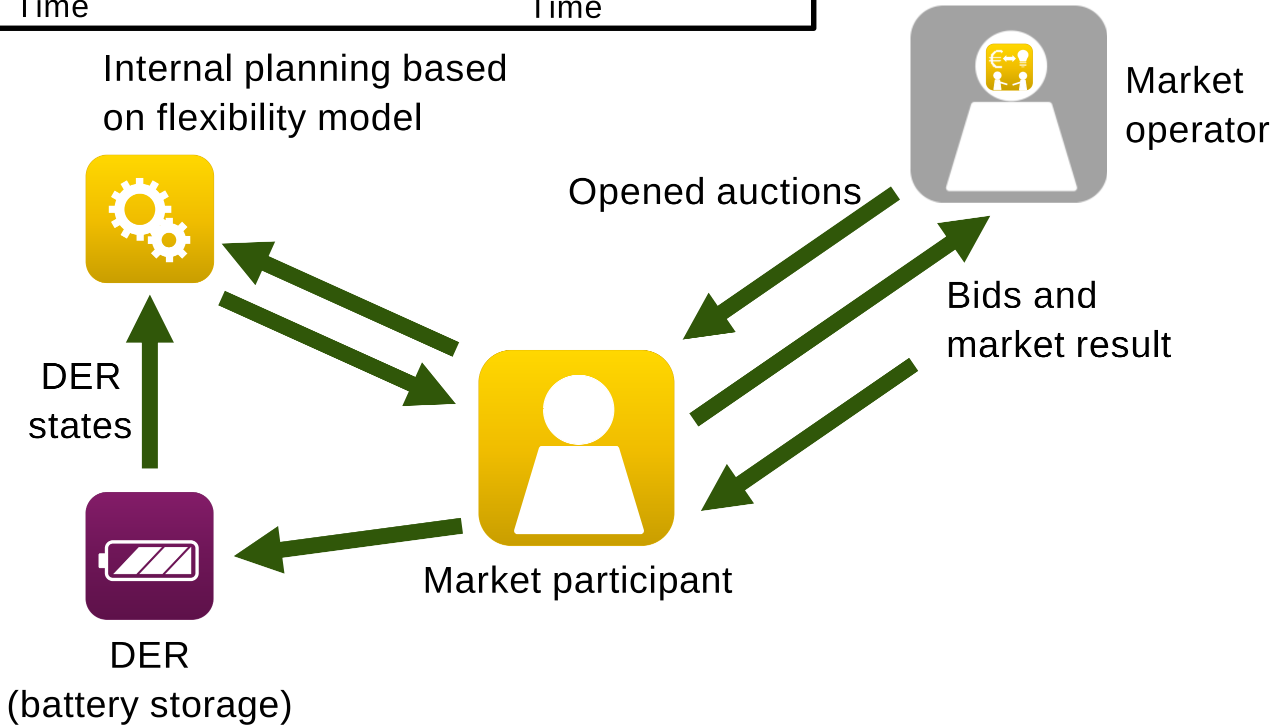
Agent-based simulation of hierarchical market



- Jointly allocate system services for transmission and distribution system
- Game theoretic evaluation
- Simulation of interdependency between market and DER states

Agent implementation to display complex system behavior





- Dedicated flexibility model from [1]
- Interdependency
  - Market ↔ DER
  - DER ↔ Bidding behavior

[1]: Tiemann, P.H., Nebel-Wenner, M., Holly, S. et al. (2022): Operational flexibility for multi-purpose usage of pooled battery storage systems. Energy Informatics 5(1), 14–26, DOI: 10.1186/s42162-022-00209-4

Contact

Carl von Ossietzky University Oldenburg, Digitalized Energy Systems Groups,

Prof. Dr.-Ing. Astrid Nieße and

Paul Hendrik Tiemann, M.Sc.,
paul.hendrik.tiemann@uol.de

2.3 – AI tools and frameworks for power flow forecasting and attack vectors on ICT infrastructures

Jana Gerlach, Sarah Lier, Prof. Michael H. Breitner

AI Tools and Frameworks for Power Flow Forecasting and Attack Vectors on ICT Infrastructures

Cybersecurity: Attacker vs. Defender

The main **cyber security threats** are: ransomware, data breaches and data loss, malware, disinformation, human error, threats to availability and integrity.

→ Costs of cybercrime include not only **monetary consequences**, but also **reputational damage** and **disclosure of data**

Traditional security measures such as antivirus programs or firewalls can **no longer** meet today's security requirements.

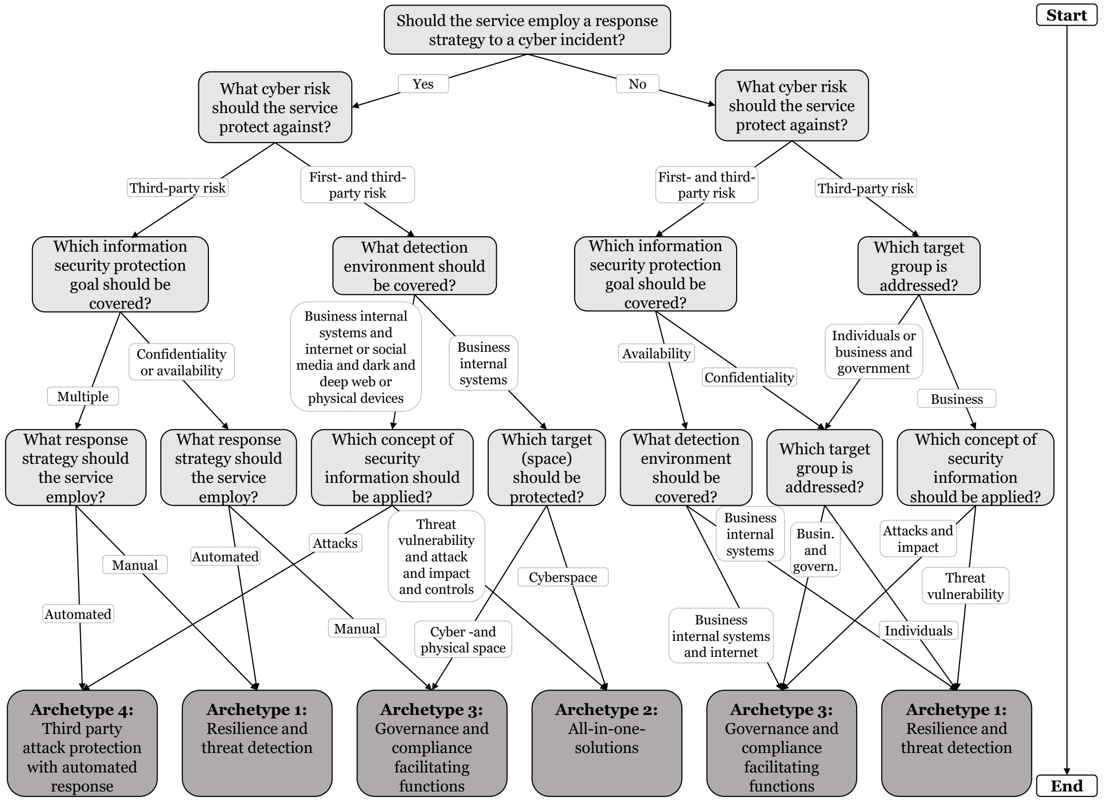
→ The need for advanced technologies such as **Artificial Intelligence** (AI) is increasing

AI for cybersecurity, e.g., Machine Learning (ML) based **anomaly detection** is an emerging service market.

→ There is a lack of classification of AI-driven cybersecurity services

→ Practitioners need a clear overview and decision support

Decision Tree for AI-driven Cybersecurity Service



Archetypes

Archetype 1 - Intrusion Detection and Resilience-Enhancing Cybersecurity Services:
- Target: Identify vulnerabilities and threats.
- Measures: Ransomware monitoring, risk assessments, backup and recovery solutions, identity management.

Archetype 2 - All-In-One-Solutions:
- Target: Providing resilience, cyberattack prevention, intrusion detection, and response in one service.
- Measures: Detect and respond to anomalies and attacks by utilizing ML technologies in real-time.

Archetype 3 - Governance and Compliance Enhancing Services:
- Target: Ensure and support governance and compliance.
- Measures: Data management, risk analysis, penetration testing, logins, and two-factor authentication.

Archetype 4 - Third-Party Attack Prevention with Automated Response:
- Target: Protection against phishing attacks, ransomware and data leaks, bot attacks, and disinformation.
- Measures: Cybersecurity awareness education by emulating threats, data leak and ransomware detection by scanning e.g., dark and deep web, connected storage devices, open databases, and cloud apps.

3 Energy Law and Economics

Topics

- **3.1 Fair pricing of ancillary services and economic potentials of controllable renewable energies**
- **3.2 Legal framework for ancillary services**

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3.1 – Fair pricing of ancillary services and economic potentials of controllable renewable energies

M.Sc. Jana Gerlach, M.Sc. Sarah Lier, Prof. Michael H. Breitner

Fair pricing of ancillary services and economic potentials of controllable renewable energies

Bidding Strategies

Plant portfolio:

- Primary control power:
  - Battery storage
- Secondary control power:
  - Positive:
    - Thermal power plants
    - Biomass power plants
  - Negative:
    - E-heaters
- Minute reserve:
  - Thermal power plants

  PV plants and other smaller plants are only offered for direct marketing, even in the pool.

Strategies:

- Primary: Day-ahead market (guaranteed off-take and security). When holding aFR, the plant cannot be marketed elsewhere lost revenues
- Intraday is risky
- Goal for participating at control reserve market: to receive revenues above the mean value = benchmark in the long term
- **Standard bids:** Before day-ahead marketing, the entire capacity is offered on the balancing power market.
  - First of all at the normal, expected power prices that can be justified.
  - The other capacities left over, which are actually intended for the day-ahead market, are still offered on the balancing power market, but at significantly higher prices.
  - Working prices are based on the marginal costs of the plants (normally the same working prices are offered. Adjusting is always possible)
  - **Lucky bids:** the last MWs are offered at very high prices, which are normally not marketable.
- **Joker bids/opportunistic bids:** Plants that are not actually on the grid are marketed at high prices in the SRL market. In the event of an award, the plant is started up, otherwise the plant remains off.
- **Aggressive bidding:** Offer high prices in the capacity market. Not being awarded a contract is no longer so bad, as the opportunity of the labour market still exists. (More of a big player strategy).

- **Exit strategy:** Offer extremely high prices to push the offer out of the merit order

 Utilization if plants are broken or other markets are more lucrative

Contact details

Institut für Wirtschaftsinformatik, Leibniz Universität Hannover

Prof. Michael H. Breitner
breitner@iwi.uni-hannover.de

M.Sc. Jana Gerlach
gerlach@iwi.uni-hannover.de

M.Sc. Sarah Lier
lier@iwi.uni-hannover.de

SiNED

Leibniz Universität Hannover | elenia Institut für Hochspannungstechnik und Energiesysteme | Carl von Ossietzky Universität Oldenburg | DLR Institut für Vernetzte Energiesysteme | OFFIS Institut für Informatik | TU Clausthal Clausthal University of Technology

3.2 – Legal framework for the procurement of demand-side flexibility for congestion management

Sebastian Buchholz, Prof. Dr. jur. Hartmut Weyer

Procurement of demand-side flexibility for congestion management

Non-market-based (mandatory) procurement mechanisms

<u>Leading question: Is remuneration owed by the grid operator to the flexibility provider?</u>

- EU Law provides for the mandatory remuneration of mandatory measures of Redispatch
- German law
  - generally also provides for compensation in the case of so called "marktbezogene Maßnahmen"
  - Exception in case of special emergencies (ultima ratio) -> no compensation
- German law on grid connection does generally not permit preventative considerations of grid congestions
  - Exception: grid connection impossible or economically unbearable; possibly applicable in case of a lack of grid capacity
  - However, German law permits a limitation of the use of the connection, in particular if the unrestricted use is based on special circumstances, the elimination of which cannot be expected of the network operator from an economic point of view
    - In particular if the network operator has already expanded the network within his duties set by law to meet demand and still congestions are to be expected
    - The flexibility provider can eliminate the economic unreasonableness for the grid operator by assuming costs incurred for the grid expansion.

Following this, the new mechanism could provide flexibility to be contracted without remuneration

Procurement of demand-side flexibility for congestion management

Non-market-based (mandatory) procurement mechanisms

Mandatory mechanism is proportionate with regards to fundamental rights concerned:

- Fundamental rights affected:
  - Freedom to conduct a business
  - Guarantee of property
  - Principle of equality

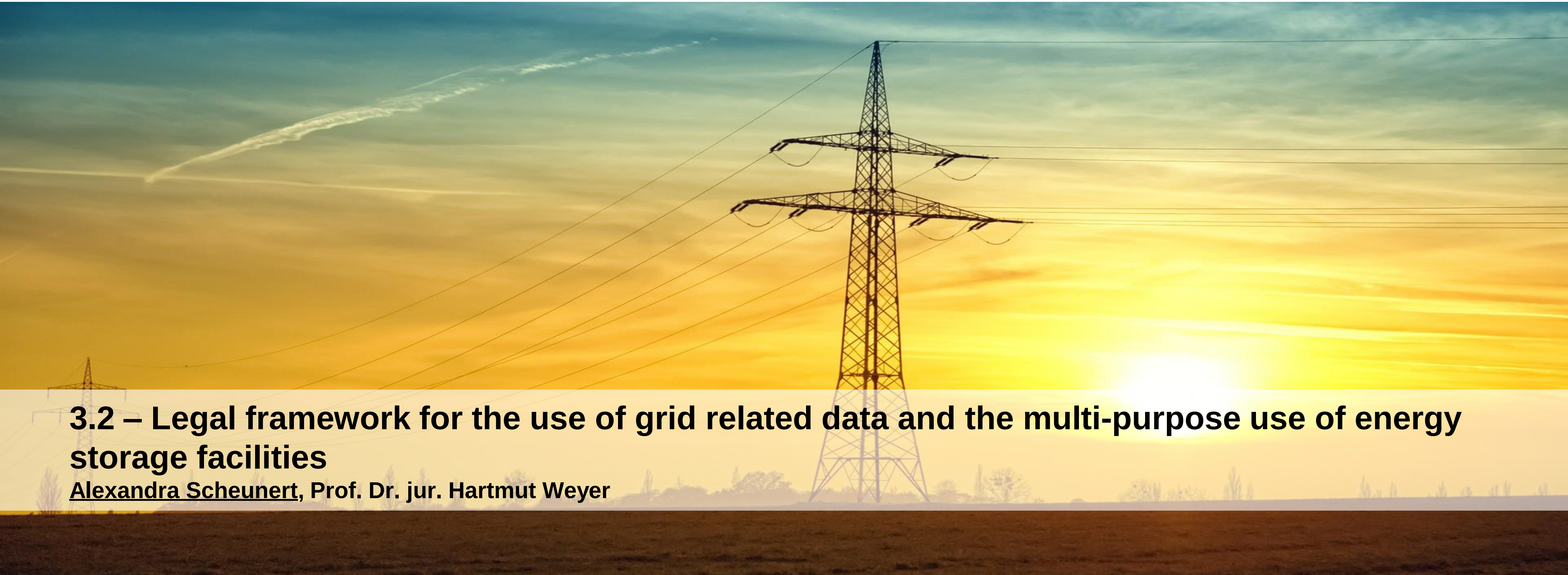
- Approaches to mitigate the intensity of the restricition of fundamental rights (Grundrechtseingriff):
  - Payment of compensation, provided that the network is not expanded to meet demand
  - The option of a second tariff is offered to the flexibility provider,
    - Tariff must enable unlimited entitlement of network use on more burdensome terms.
    - The tariff that allows the network operator extensive recourse options is granted on better terms.

Contact details

Technische Universität Clausthal
Institut für deutsches und internationales Berg- und Energierecht

Prof. Dr. Hartmut Weyer
hartmut.weyer@tu-clausthal.de
tel.: +49 5323 72-5035

Sebastian Buchholz
sebastian.buchholz@tu-clausthal.de
tel.: +49 5323 72-5038



3.2 – Legal framework for the use of grid related data and the multi-purpose use of energy storage facilities

Alexandra Scheunert, Prof. Dr. jur. Hartmut Weyer

Legal framework for the use of grid-related data

- Background of regulation:
  - Protection of personal data
  - Protection of sensitive information about the grid and power system
  - Ensuring necessary data reaches relevant parties
  - Cybersecurity
  - Protection of competition

- Legal grounds for processing of personal data required, e.g.
  - Consent – can be withdrawn at any point
  - Required to fulfill a contract or in preparation of a contract the affected party initiated
  - Necessary to fulfill a legal obligation or a task in the exercise of official authority vested in a grid operator
  - Legitimate interests that are not overridden by interests or fundamental rights and freedoms of data subject

- Parties, that may handle personal data: conclusively listed
  - Listed: e.g., Grid operator, balancing responsible parties, etc.
  - Not listed: new market roles, e.g. aggregators
  - If not listed: processing of personal data only based on consent

- Specific purposes of data processing required
  - GDPR: any purpose sufficiently specified in advance
  - German MsbG:
    - only certain purposes
    - e.g. data use by balancing responsible party only for the purpose of:
      - Balancing group management,
      - Verification of balancing group billing, or
      - Fulfillment of duties set forth by the German Federal Network Agency

- Especially: data processing in Blockchain
  - Data received by all participants
    - not only by parties permitted to process data (by national law)
    - data processing (only) based on consent?
  - Purpose of data processing:
    - Only for those parties involved in a certain transaction
    - Data processed for technical purposes by all other participants
    - Possible conflict with the requirement of a specific purpose of data processing
  - Possible solution: private or permissioned Blockchain

Legal Framework for the multi-purpose-use of electricity storages

- EEG-surcharge dropped in July 2022

- Remaining financial burdens:
  - Network charges
    - apply for consumption
    - Electricity storage in Germany defined as: consumption and production of energy
    - ⇒ network-charges apply for the consumption in the storage facility as well as for the final consumption elsewhere
    - Exceptions for electricity storage facilities:
      - Generally no network charges for electricity stored in facilities built in certain time periods
      - However no exception for storages after 20 years of operation
      - Possibly no exception, if the energy stored is not fully fed back into the grid (e.g. if parts of the energy stored are consumed within the household)
  - Similar consideration for electricity taxes and the new hydrogen surcharge

- Principle of exclusivity:
  - Funding for electricity storage facilities exists, so called “EEG-Förderung”
  - Require the entire energy stored to stem “exclusively” from renewable energy sources
    - Simultaneous storage of energy stemming from renewable energy sources and other sources probably conflicts with the principle of exclusivity
    - However, if only the energy stored at a certain point in time must “exclusively” stem from renewable energy sources, a sequential use of energy from other sources is possible
  - Might stand in contrast to European regulations requiring the Member States to encourage energy storage solutions

Contact details

Technische Universität Clausthal
Institut für deutsches und internationales Berg- und Energierecht

Prof. Dr. Hartmut Weyer
hartmut.weyer@tu-clausthal.de
tel.: +49 5323 72-5035

Alexandra Scheunert
alexandra.scheunert@tu-clausthal.de
tel.: +49 5323 72-2388

Conclusion and Outlook

Conclusion

Electrical Power Engineering

- Results of Investigation of different voltage levels and fault handling
- Flexibility potential of prosumers for ASs: algorithms for distributed devices and a simulative and hardware-based validation environment was built
- The aggregation of distribution grid flexibilities for usage in operation of overlaying grid levels is proposed and in dynamic analyses, FCR techniques from DERs are investigated
- The evaluation of protection and control systems shows that further development of distance protection systems are necessary to ensure a safe and reliable provision of ASs with increasing inverter-based infeed
- The prospective, distributed provision of ASs in a digitalized way requires developing IT and corresponding ICT infrastructures

Digital Transformation / Information and Communication Technology

- Decentralized market architecture for the resilient provision of ASs were developed and implemented for an agent-based simulation
- Results on cyber security aspects of ICT infrastructures in the form of cyber-attack vectors and cyber security strategies
- The bid-based design of the AS market influences the financial factors of the market in terms of the scope and diversity of the asset portfolio and the risk aversion of the marketer

Energy Law and Economics

- There are forms of procurement of flexibility, market designs, data use as well as battery storage applications that allow to meet the demands of a transitioning energy system

→ **results indicate the technical, economics and regulatory feasibility of the future provision of AS by DER**

Research Project SiNED Insights – Ancillary Services for Reliable Power Grids in Times of the Progressive German Energiewende and Digital Transformation

Contact Details

elenia Institute for High Voltage Technologies and Power Systems
Prof. Dr.-Ing. Bernd Engel

- Phone: + 49 531 391 7788
- Mail: cornelius.biedermann@tu-braunschweig.de
- Web: https://www.efzn.de/de/forschung/efzn-forschungslinien-und-querschnittsforschungsbereiche/efzn-forschungsverbuende-und-kompetenznetzwerke/sined/