Friedrich-Alexander-Universität
Technische Fakultät

Lehrstuhl für
Elektrische Energiesysteme

The Transition of the German Power System: Challenges and Solutions

RTDS European Users Group Meeting
Nuremberg - 20 September 2023

Prof. Dr.-Ing. Matthias Luther

Contents

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Quick facts about the University

Full-spectrum university with 5 faculties, including a University Hospital

> 39,650 students

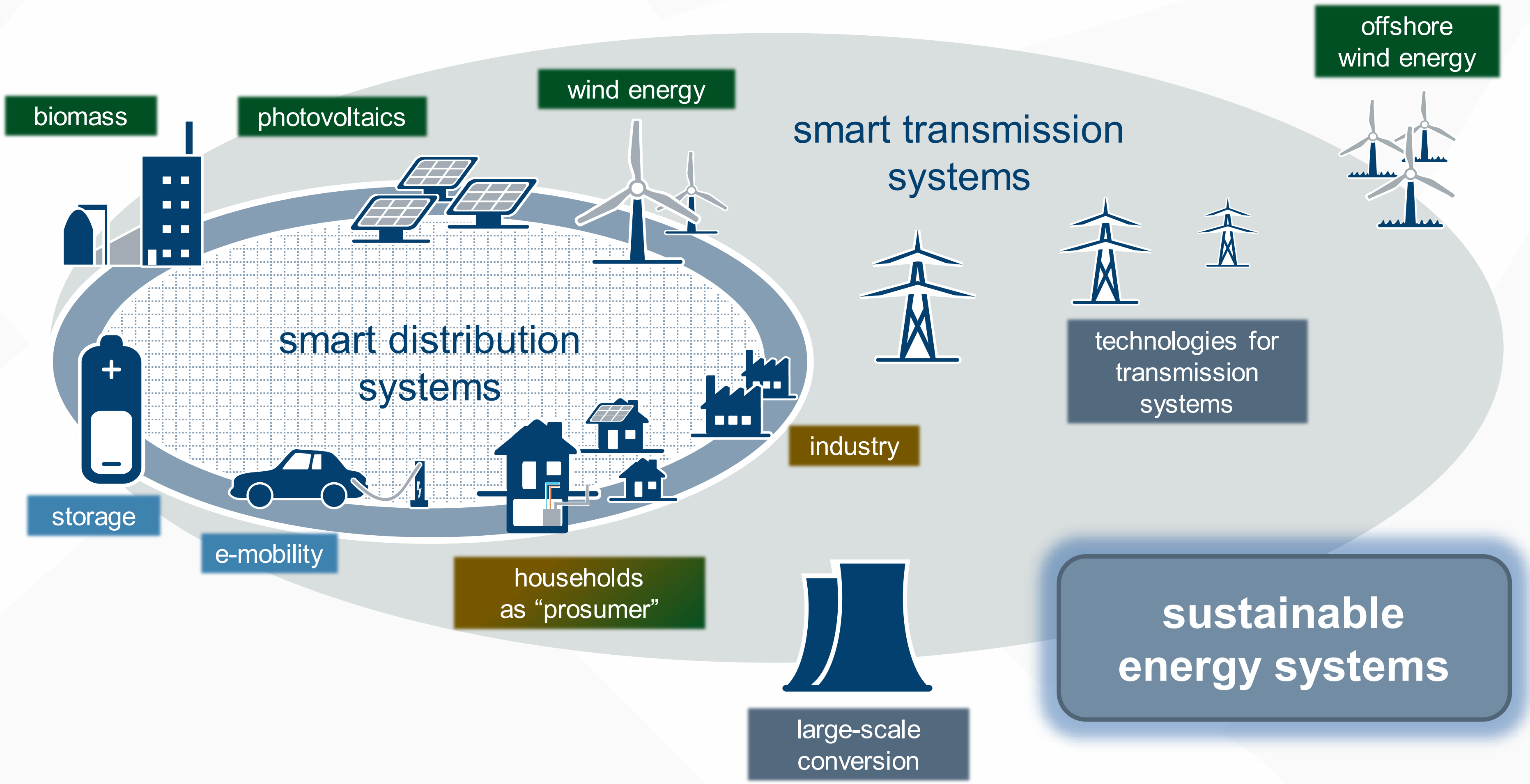
~ 630 professorships

> 3,600 academic staff members

> 272 degree programs, among them

- > 82 Bachelor's degree programs
- > 98 Master's degree programs
- > 42 degree programs taught in English
- > 14 double degree programs

Our research concept: overall system analysis



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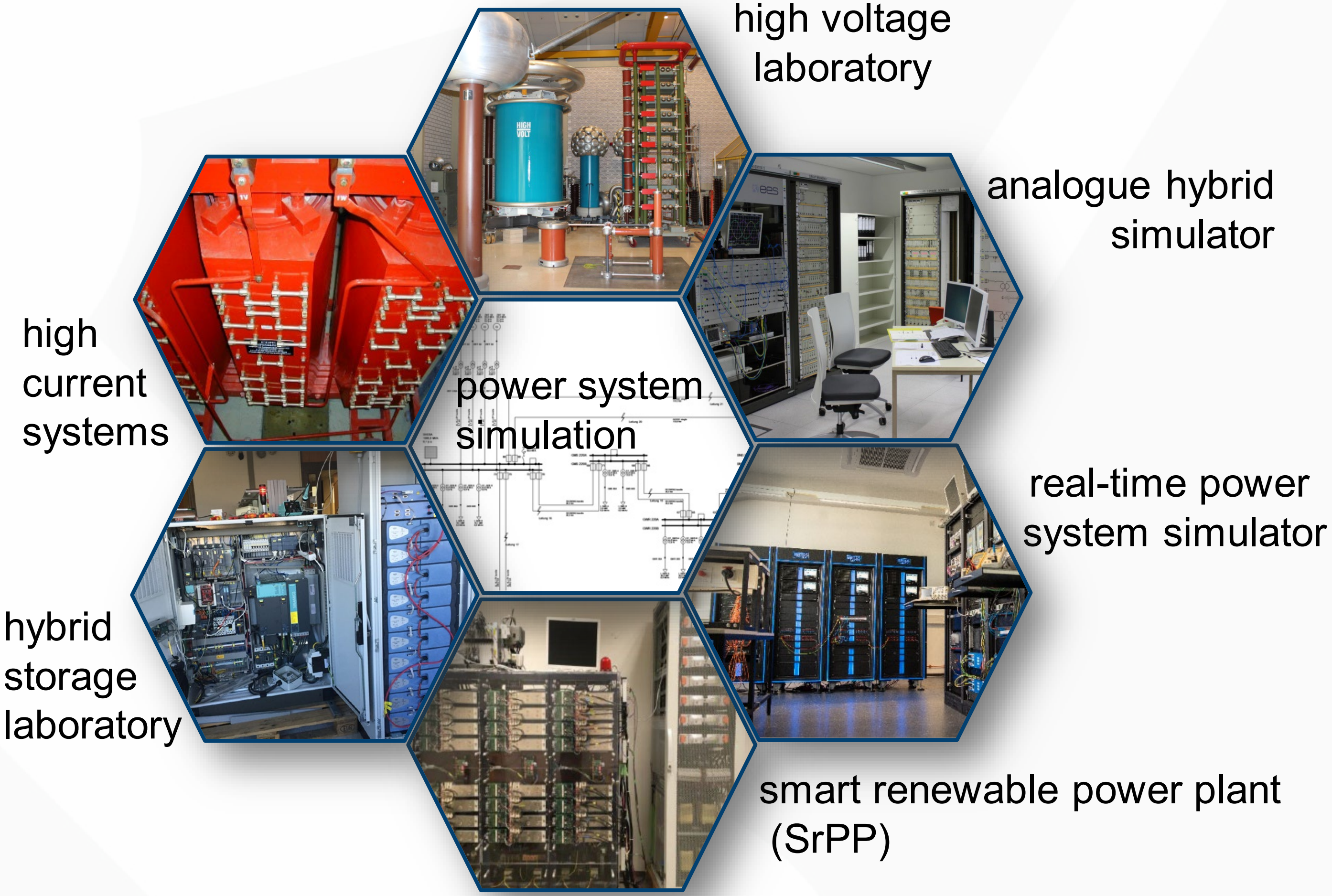
Methods and tools for research

- Hardware/software coupling: merging the analogous and digital world
- Combination/verification of simulations and measurements
- Adaptation and extension of laboratories according future system structures



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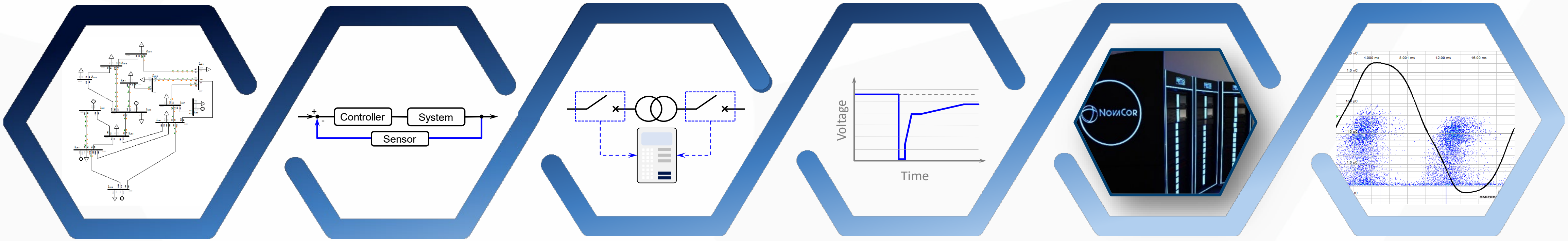
Our value chain: research topics in the overall system design



Power System Planning	Control Development	Protection Schemes	Grid Compliance Study & Analysis	Control Validation	High Power Technologies
Network Modelling	Research & Design Development	Special Algorithms	Dynamic Stability	Model-in-the-loop	High Voltage Tests
Scenario Development	Control Structure Model	Voltage & Frequency	Fault-ride-through Capability	Software-in-the-loop	High Current Tests
Network Reduction	Simulation Models	Over/Under Current	Security & Ancillary Services	Hardware-in-the-loop	Prototype Development
Automation					

RTDS image source: https://www.rtds.com/technology/simulation-hardware/

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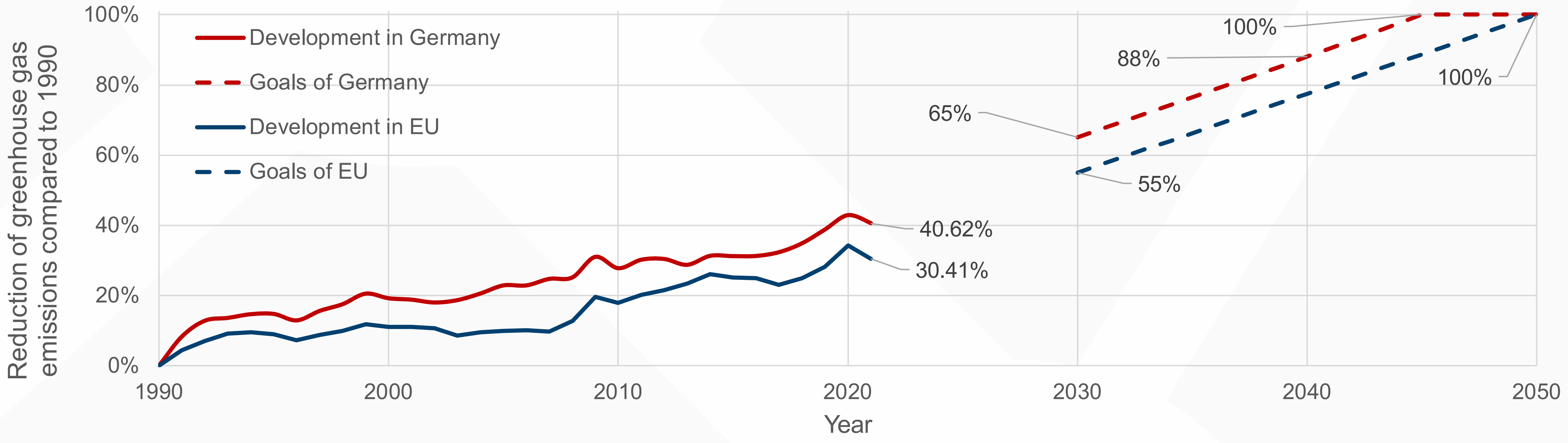
European key figures for GHG reduction

- European Union (EU)
  - „European Climate Law“:

    Climate-neutral by 2050

- Germany
  - „Bundes-Klimaschutzgesetz“ (German Climate Law):

    Climate-neutral by 2045



Source: European Environment Agency
European Climate Law
Bundes-Klimaschutzgesetz

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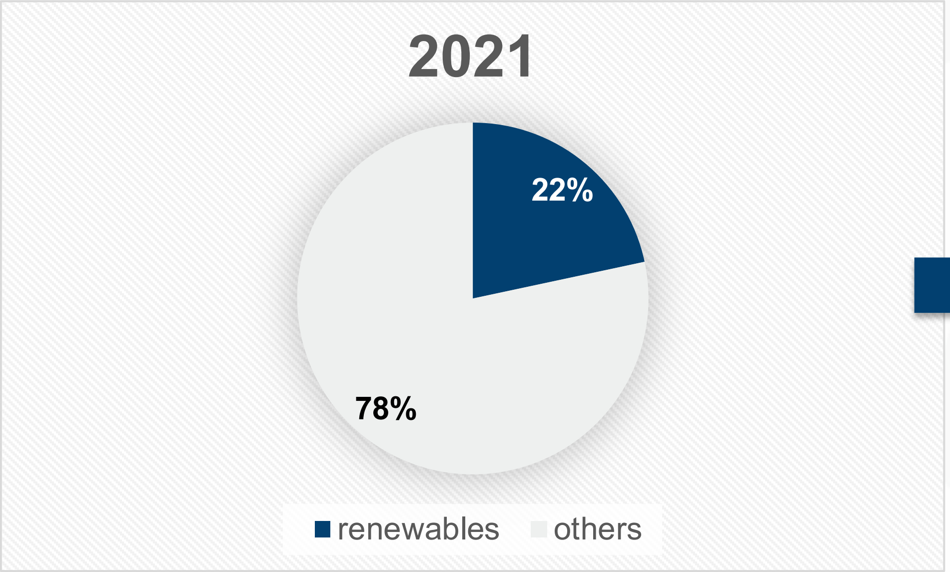
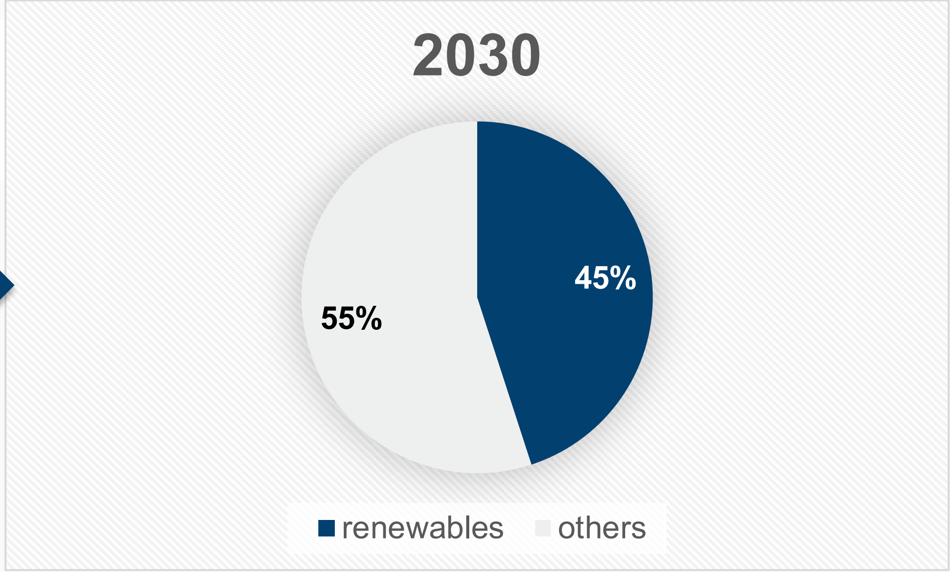
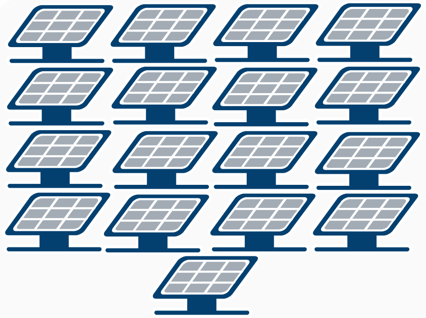
European target for integration of renewables (RED III)

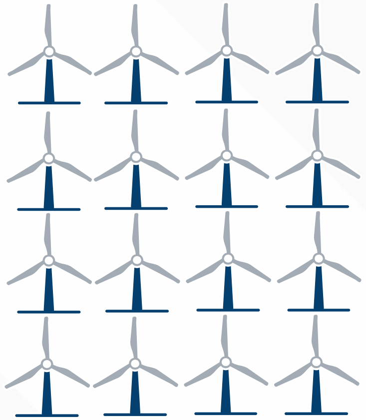




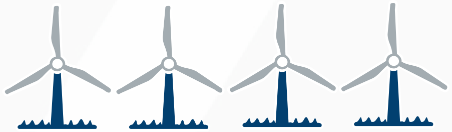
Construction of



17 football pitches pv systems



16 wind turbines onshore



4 wind turbines offshore

every day!

Source: German Federal Ministry for Economic Affairs and Climate Action

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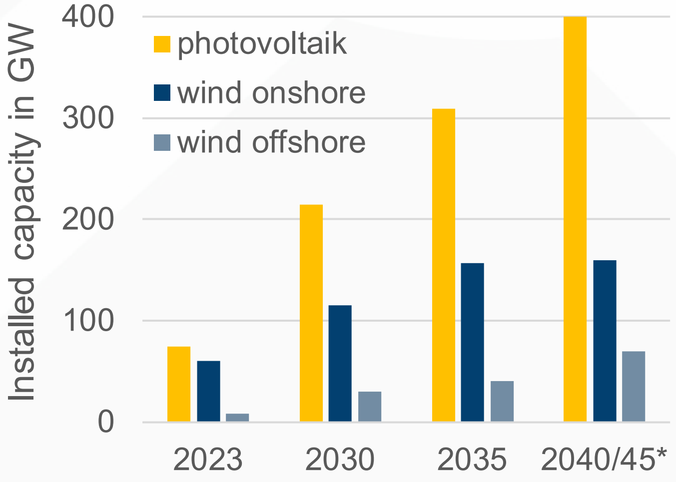
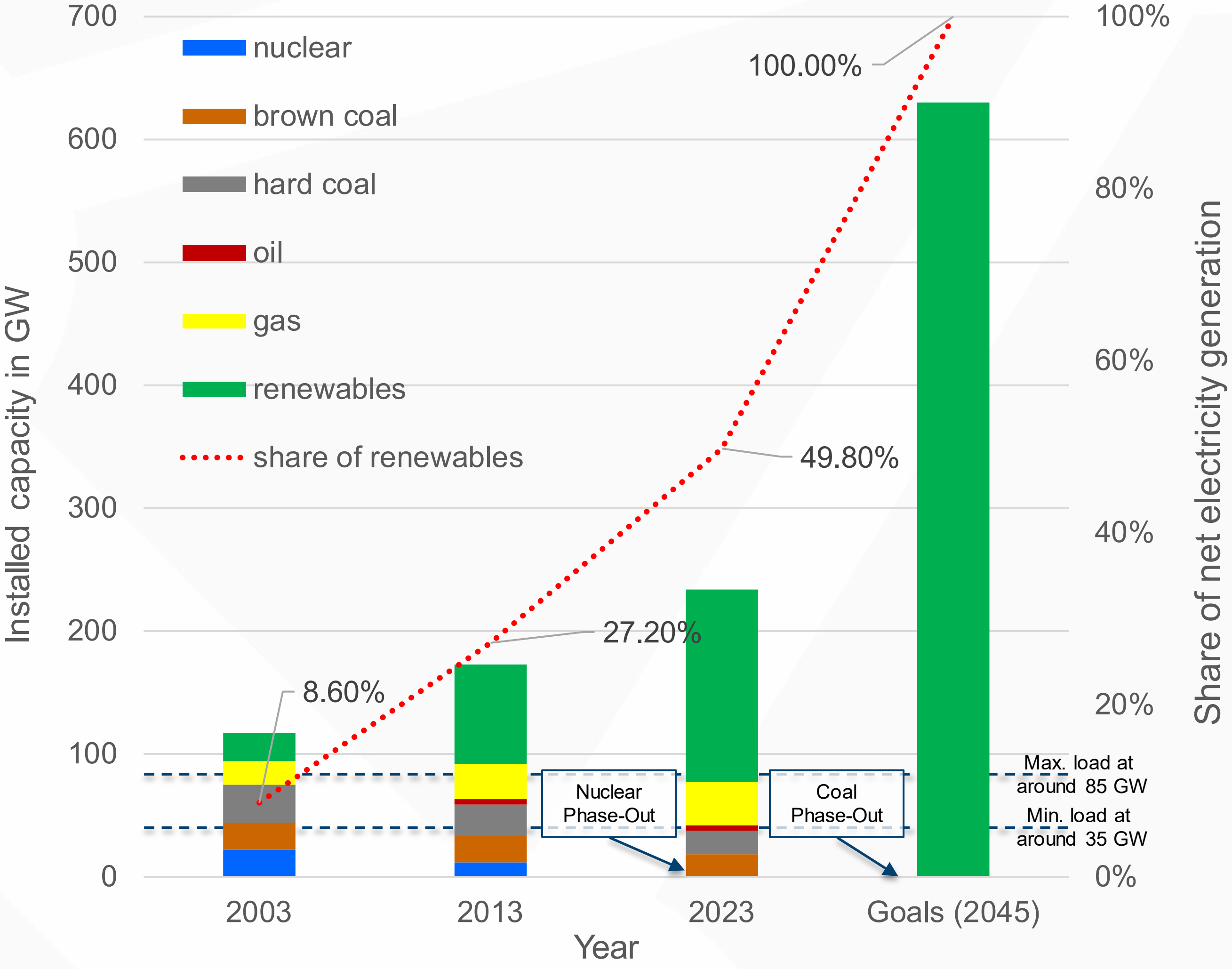
Power generation planning in Germany until 2045

- Shut down of thermal power plants
  - Nuclear: April 2023
  - Coal: 2038 (at the latest)

- Expansion of renewable generation





Source: Energy-Charts, Fraunhofer-Institut für Solare Energiesysteme
Erneuerbare-Energien-Gesetz
Windenergie-auf-See-Gesetz

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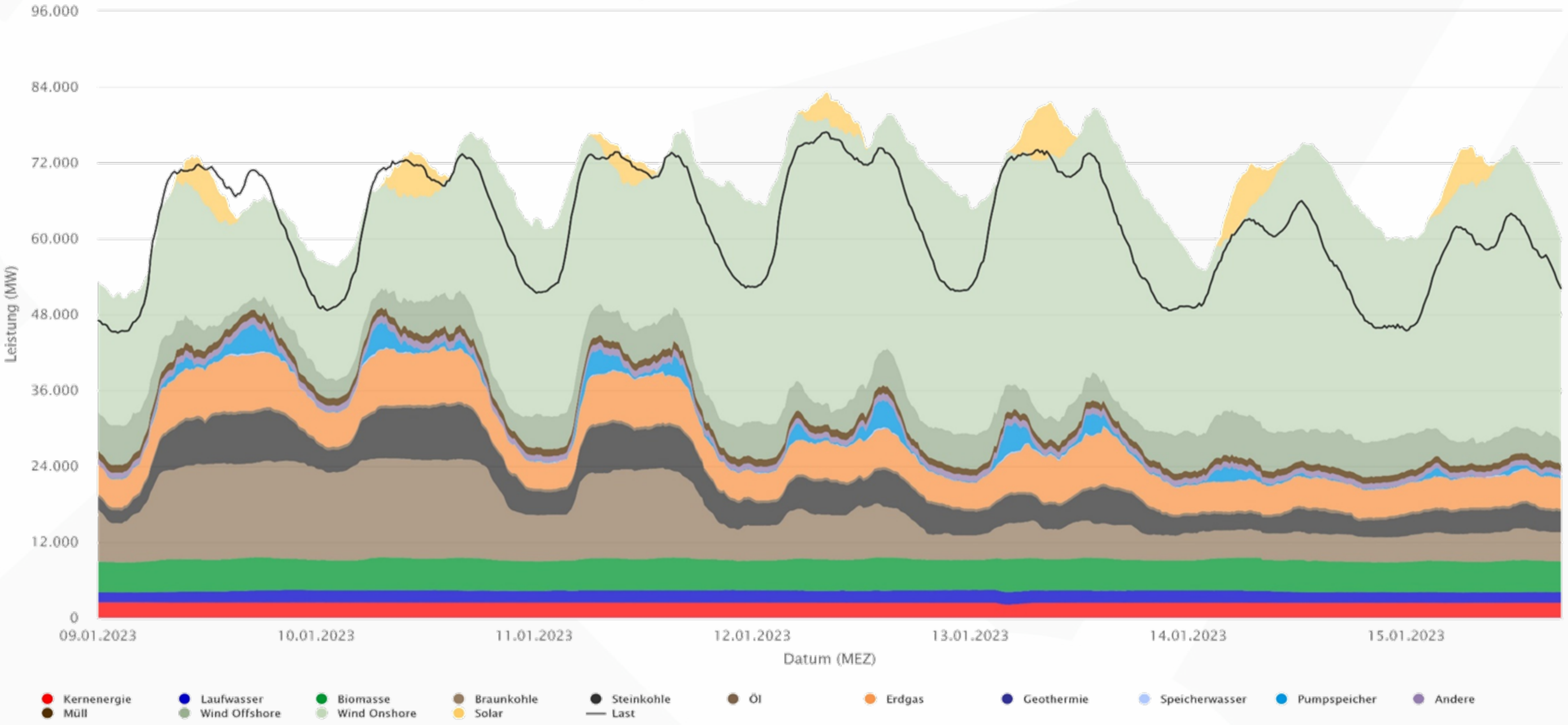
Generation and consumption in Germany: winter 2023

Low photovoltaics and high wind infeed



Source: Energy-Charts, Fraunhofer-Institut für Solare Energiesysteme

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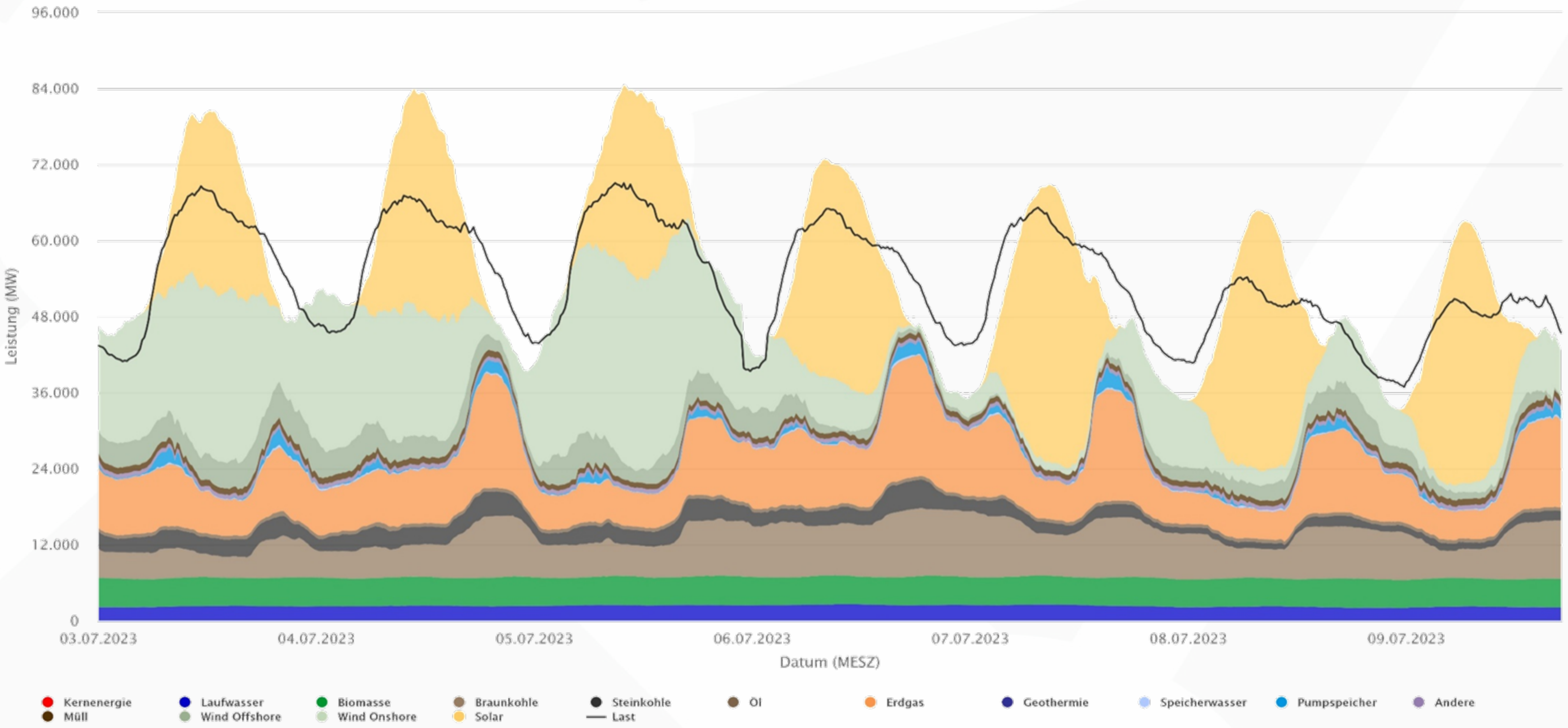
Generation and consumption in Germany: summer 2023

High photovoltaics infeed and fluctuating wind generation



Source: Energy-Charts, Fraunhofer-Institut für Solare Energiesysteme

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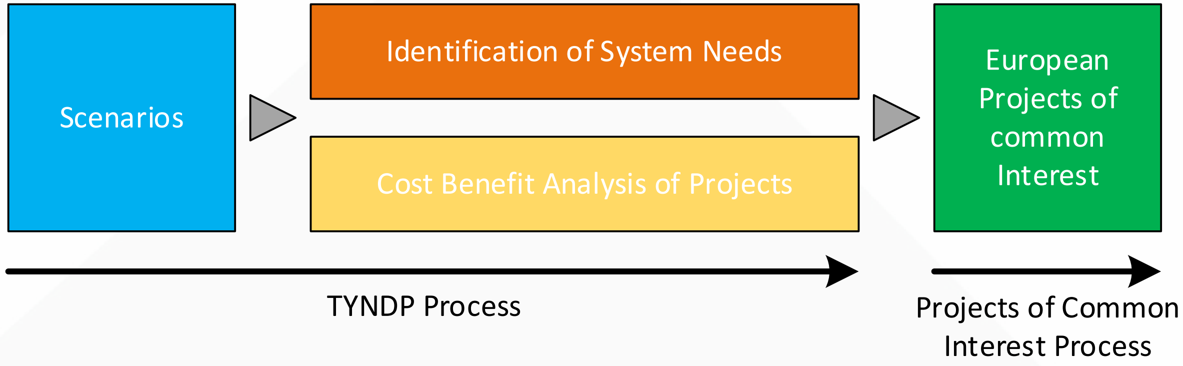
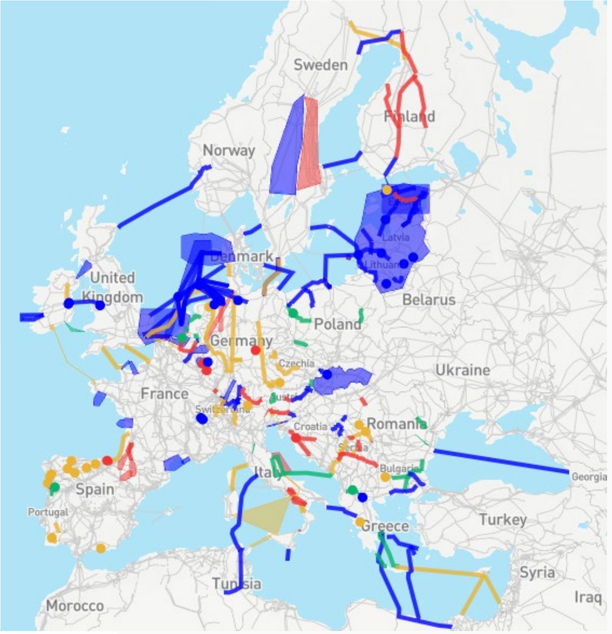
ENTSO-E: The Ten Year Network Development Plan (TYNDP)

entsoe

- Why is a European Network Development Plan being prepared?
  - Achieving the climate targets (emission-free in 2050) and safe grid operation
  - Support and complement national network development plans
  - European vision of the future electricity system
- Development of the TYNDP



- Key figures
  - 164 transmission and storage projects assessed
  - 91 GW cross-border capacity increases by 2030
  - 1.6 million jobs created by the development of electricity infrastructure projects in the EU
- TYNDP 2022 Projects



Source: ENTSO-E,TYNDP

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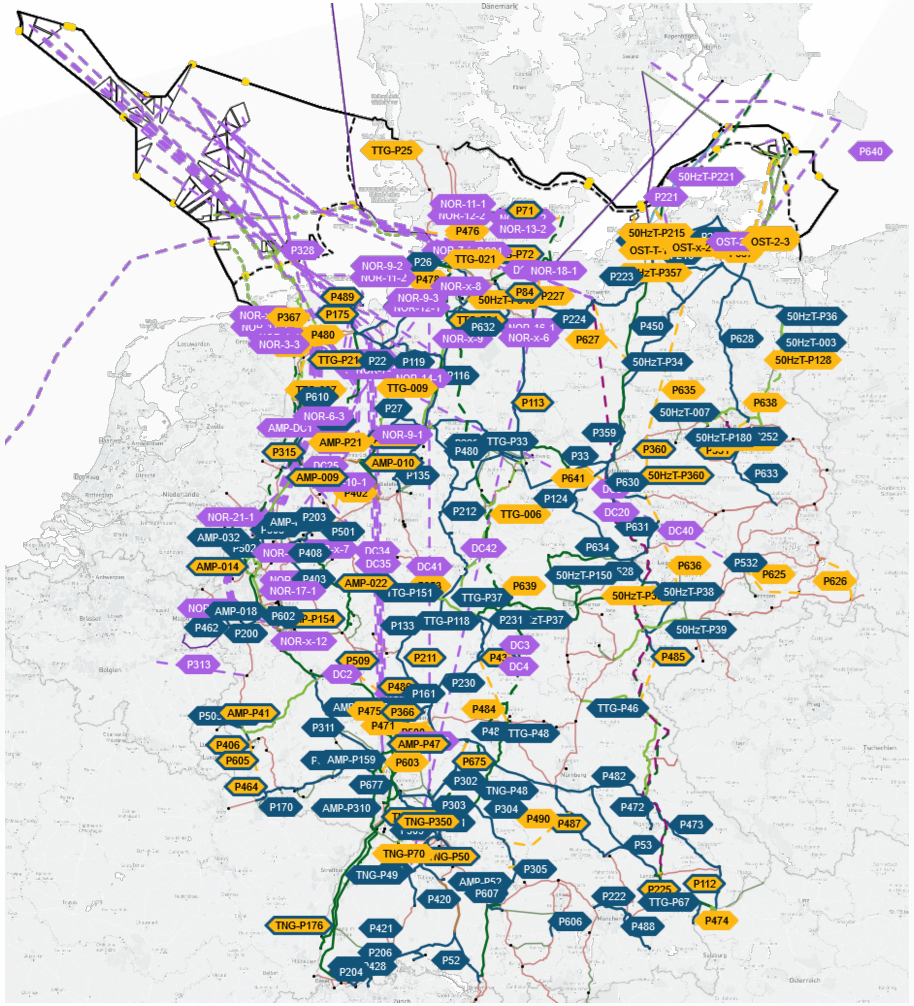
The German Network Development Plan ("Netzentwicklungsplan Strom")

- To be prepared by the four German TSOs in accordance with the resolution of the "Bundestag" in August 2011
- Network development plan in a two-year cycle since 2012
- Progressive changes in the operating environment of the electric power system
- The GNDP should include the measures necessary for safe and reliable network operation
- Review and approval by the German regulator: Bundesnetzagentur (BNetzA)
- A key component of the "Bundesbedarfsplan"



Source: NEP 2037/2045 (2023)

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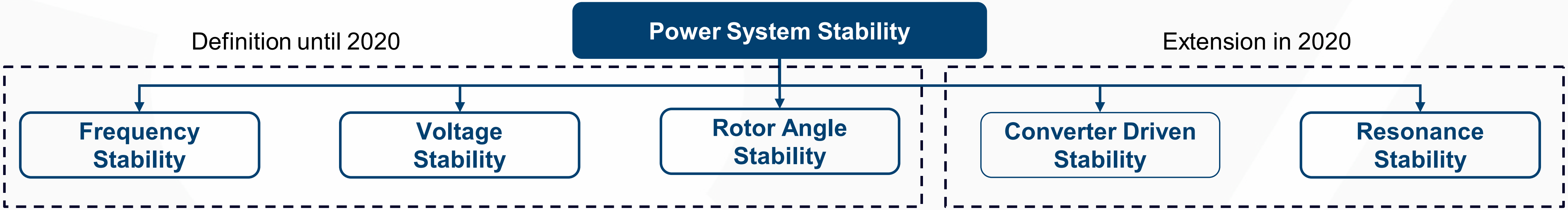
Dynamic stability analysis of hybrid grid structures

Classification according to IEEE and CIGRE



- In the past, stability considerations were mainly limited to the time domain of **electromechanical** interactions
- Voltages and currents could be considered as **steady-state phasors**
- Dynamics of the power system only defined by **control systems** and **machine equations**

- **Power electronics** are increasingly integrated into power systems today
- Power electronics significantly impact system stability

Source: IEEE, Definition and Classification of Power System Stability – Revisited & Extended

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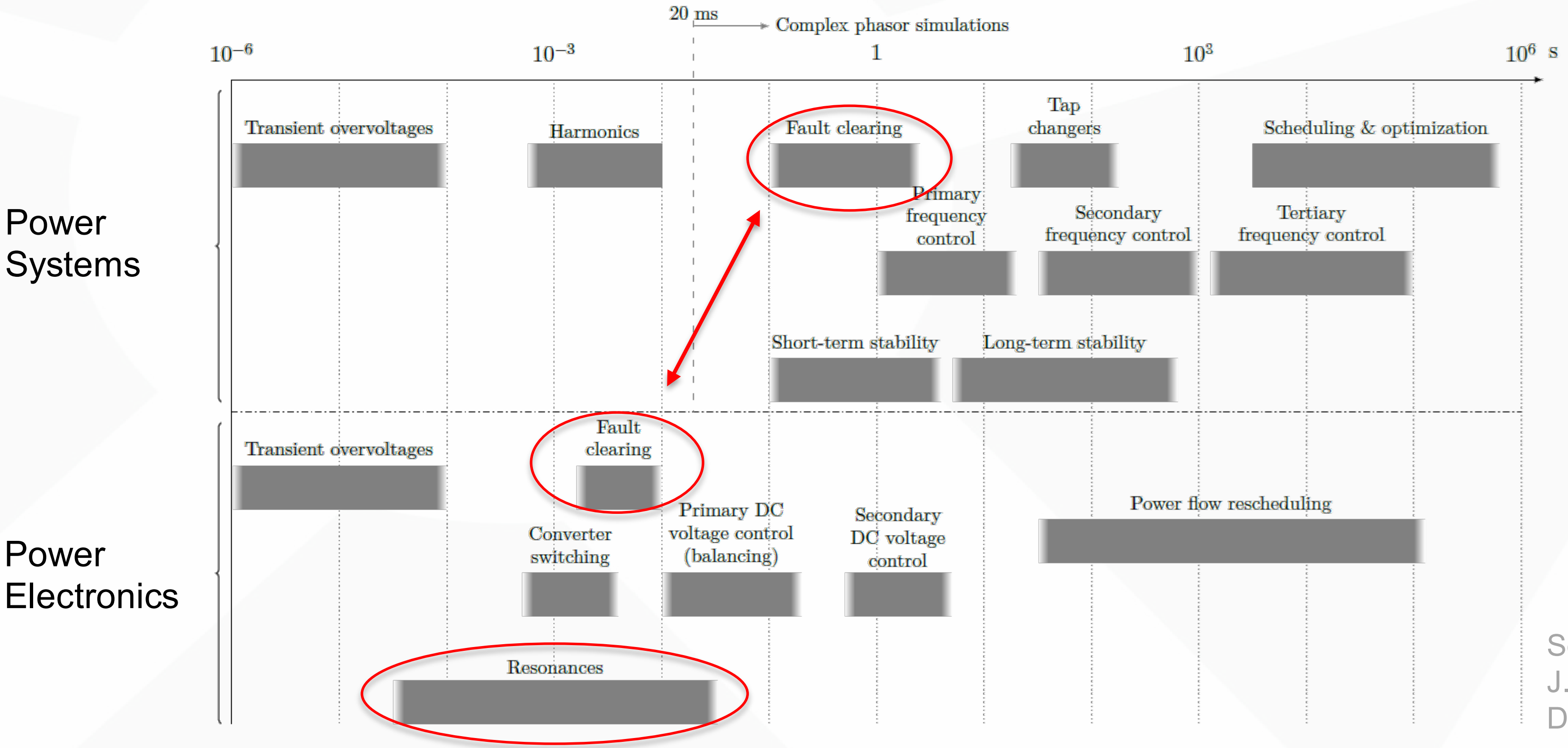
Dynamic stability analysis of hybrid grid structures

Impact of power electronics on the interaction time frames



Source:
J. Beerten – Modeling and Control of DC Grids
D. V. Hertem – HVDC grid developments

- Integration of new technologies
- Significantly faster system components
- New system interactions

New system structures and extended system models require innovative methodologies and tools

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Real time system operation: the curative (n-1)-criterion

Higher utilisation of existing grid infrastructure

Preventive

- The grids will be planned with (n-1) security for the undisturbed operation - i.e. designed with redundancy.
- The redundancy will be held for a contingency in all grid equipment.

− Easy and proven application in planning and operation

− Partial loading of assets in undisturbed operation

− Deterministic approach without considering the probability of occurrence of (n-1) contingencies

Curative

- The (n-1) principle will be maintained „curative“, i.e. after a disturbance by operative interventions.
- There will be no or limited redundancy in the undisturbed operation.

− High complexity and necessity of additional operational degree of freedom (flexibility options, automatization)

− Maximum loading of assets in the undisturbed (steady-state) operation

− Increase of transmission capacity in the steady-state operation, long-term reduction of demand for grid extension

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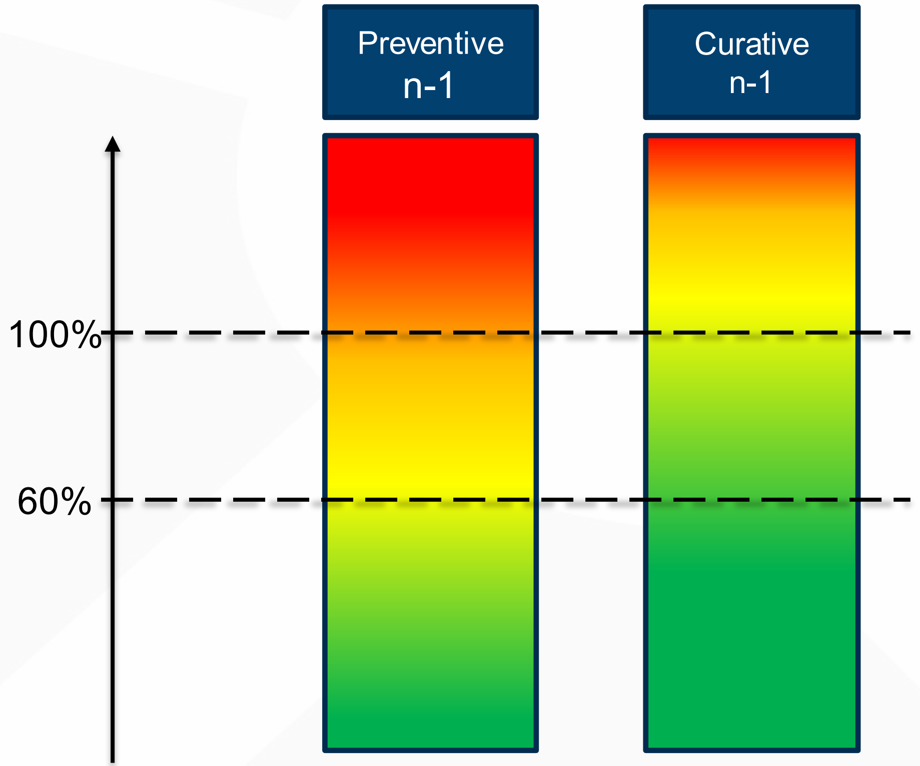
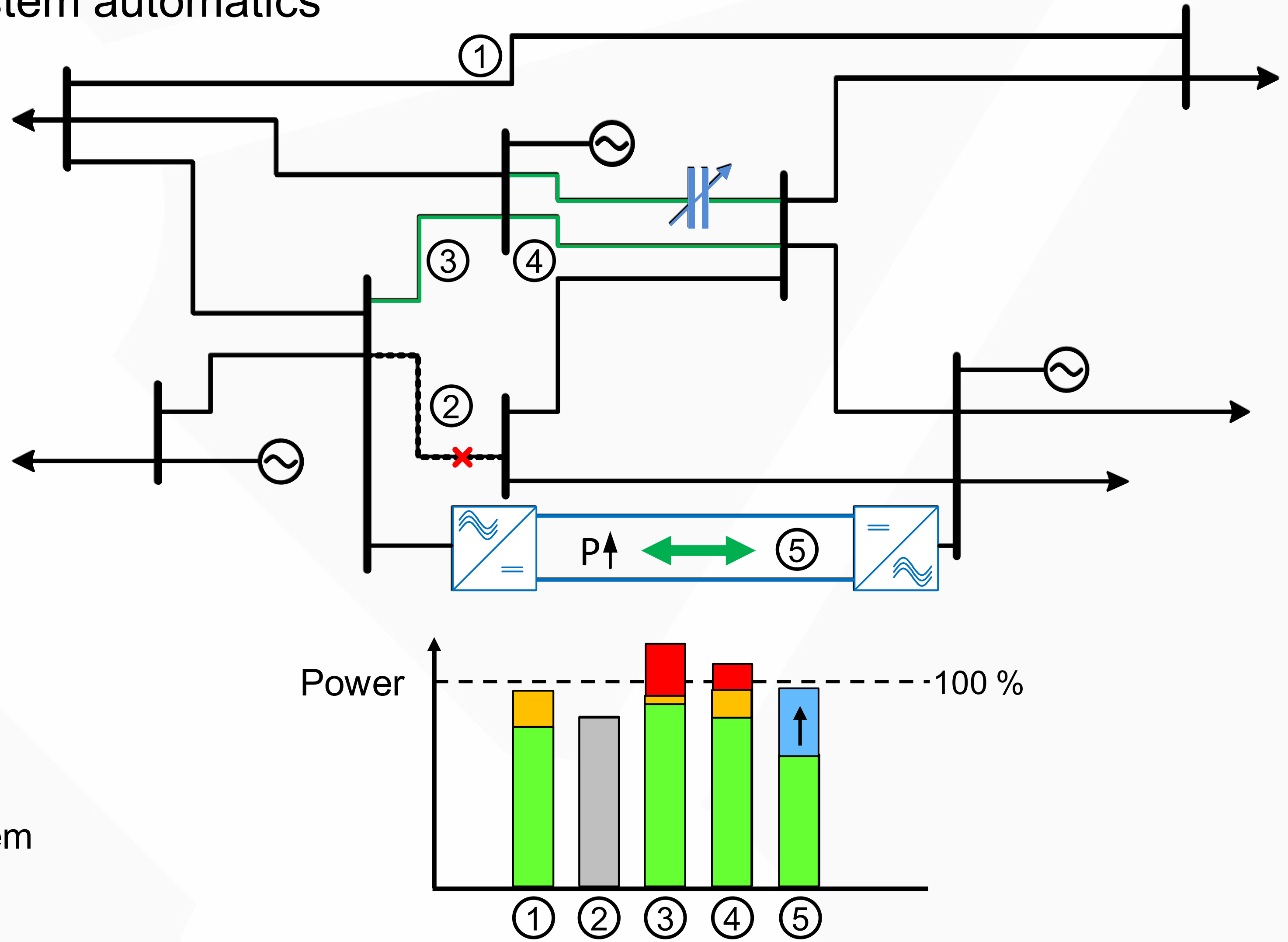
Real time system operation: curative fault clearing

Example: real time fault clearing by system automatics





- Temporary overload is allowed
- Return to (*n-1*) secure operation with system automations and curative measures.

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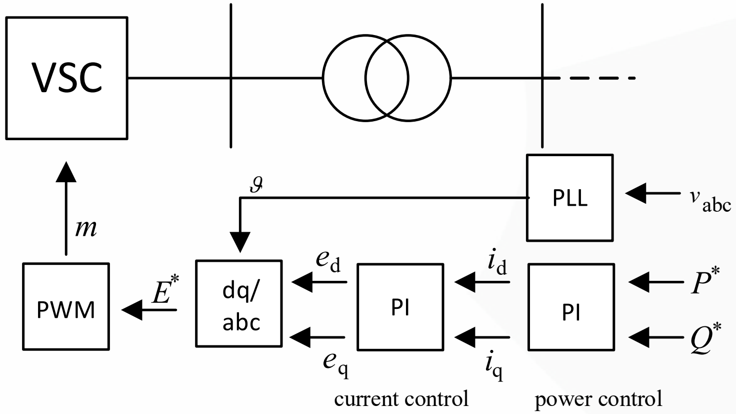
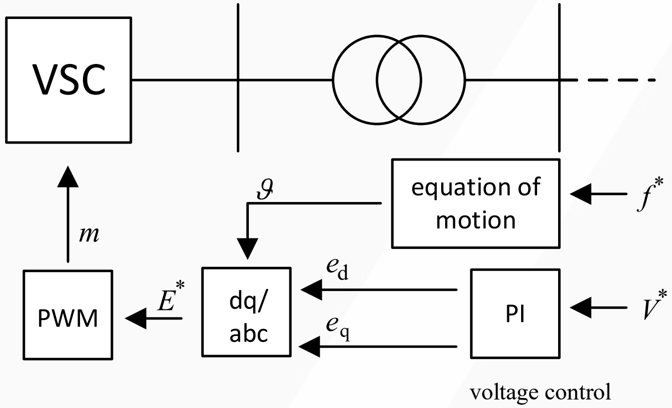
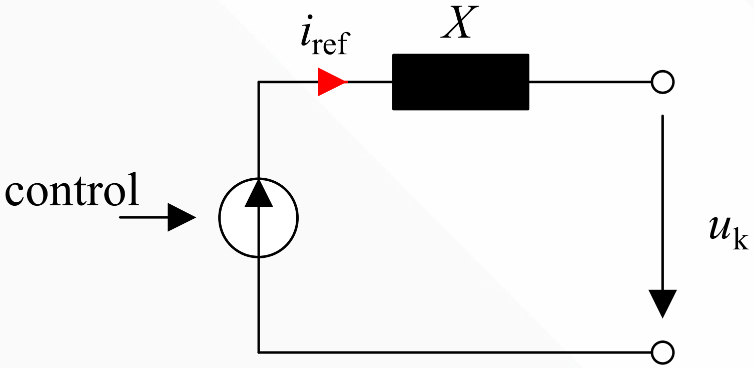
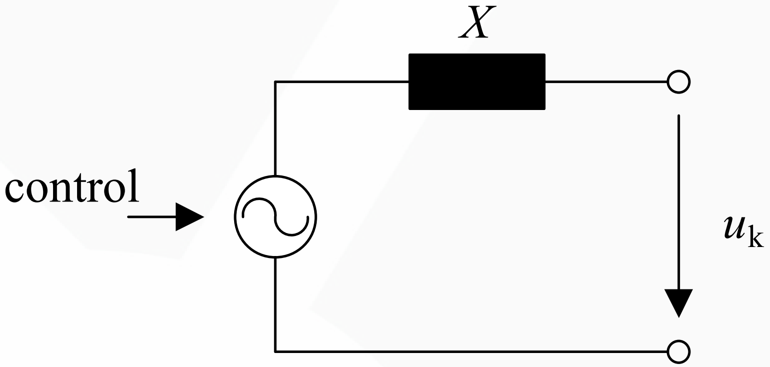
Advanced converter design and control

	Grid-following control	Grid-forming control:
Control concept		
Grid behaviour		









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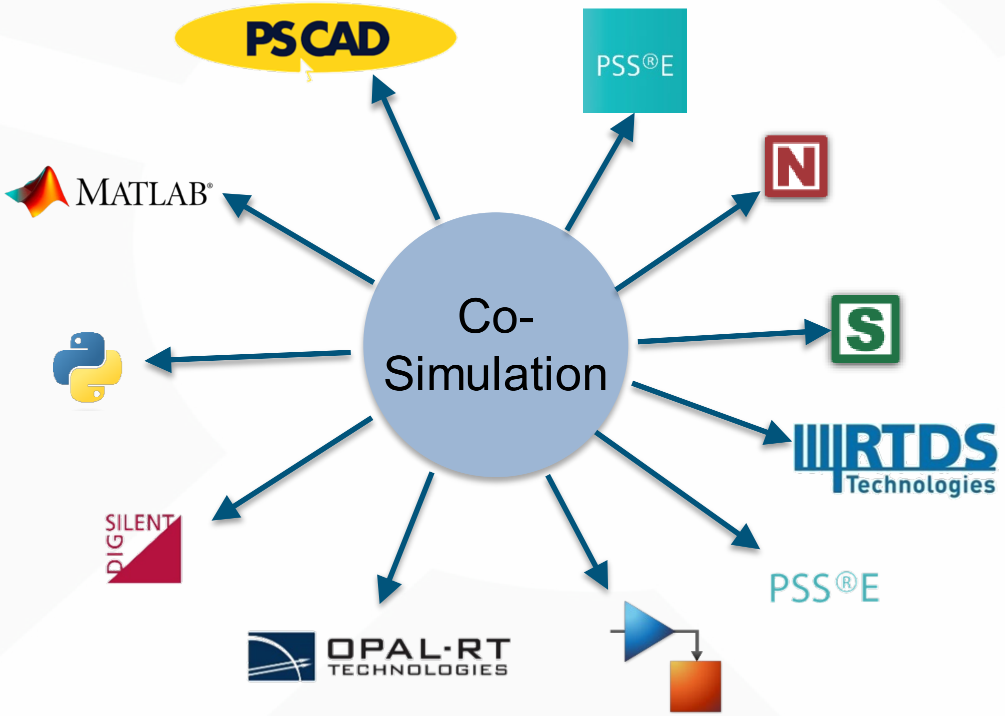
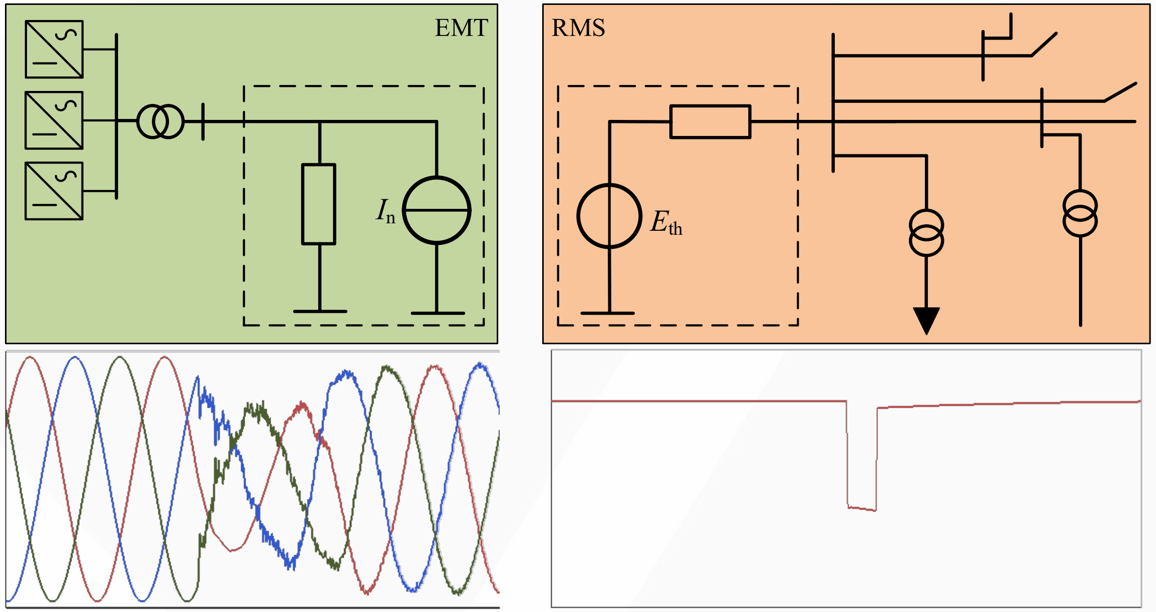
Co-Simulation: Linking various simulation tools and methods





Advantages of Co-Simulation

- No need to convert models between programs or simulation types (RMS, EMT)
- Leverage the strengths of each simulation tool

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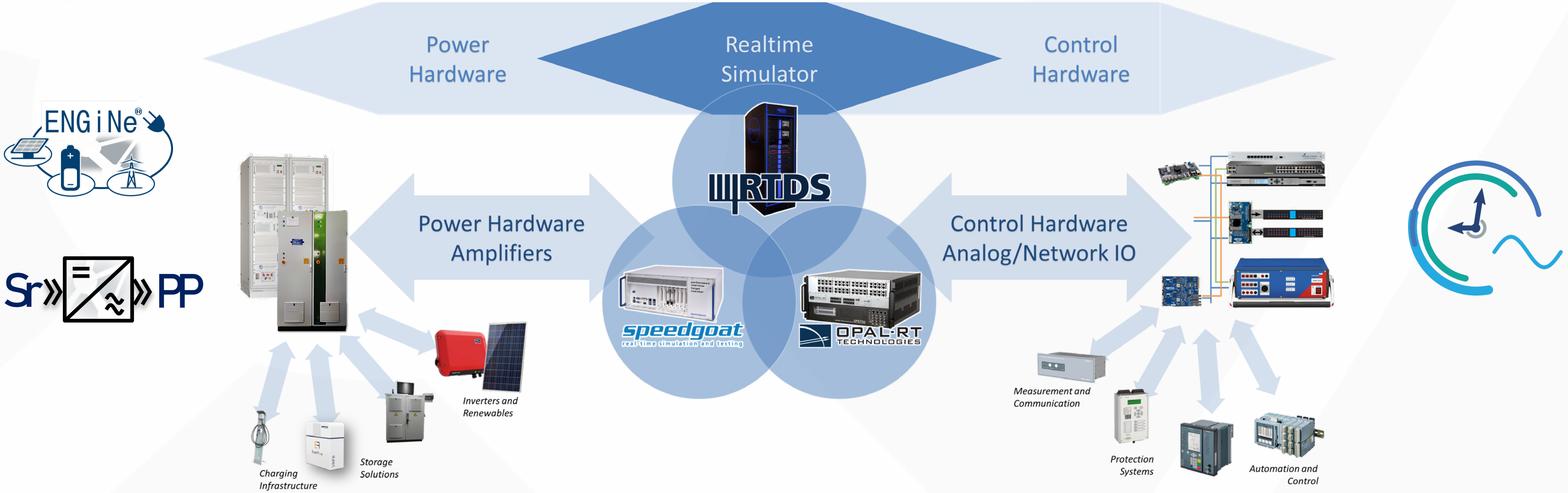
Real time analysis – a new era in power system planning and operation

Setup and components of our RTA lab in Nuremberg



Benefits from realtime simulation:

- hardware analysis under realistic grid conditions
- cost- and time effective testing
- on-site development of equipment and control
- training of staff, e.g. system operators

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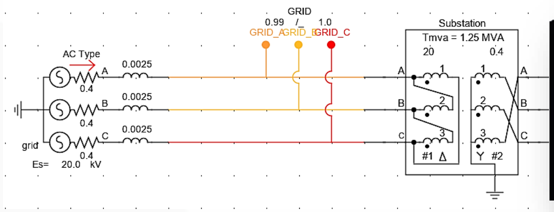
Example: compliance test of converter integration

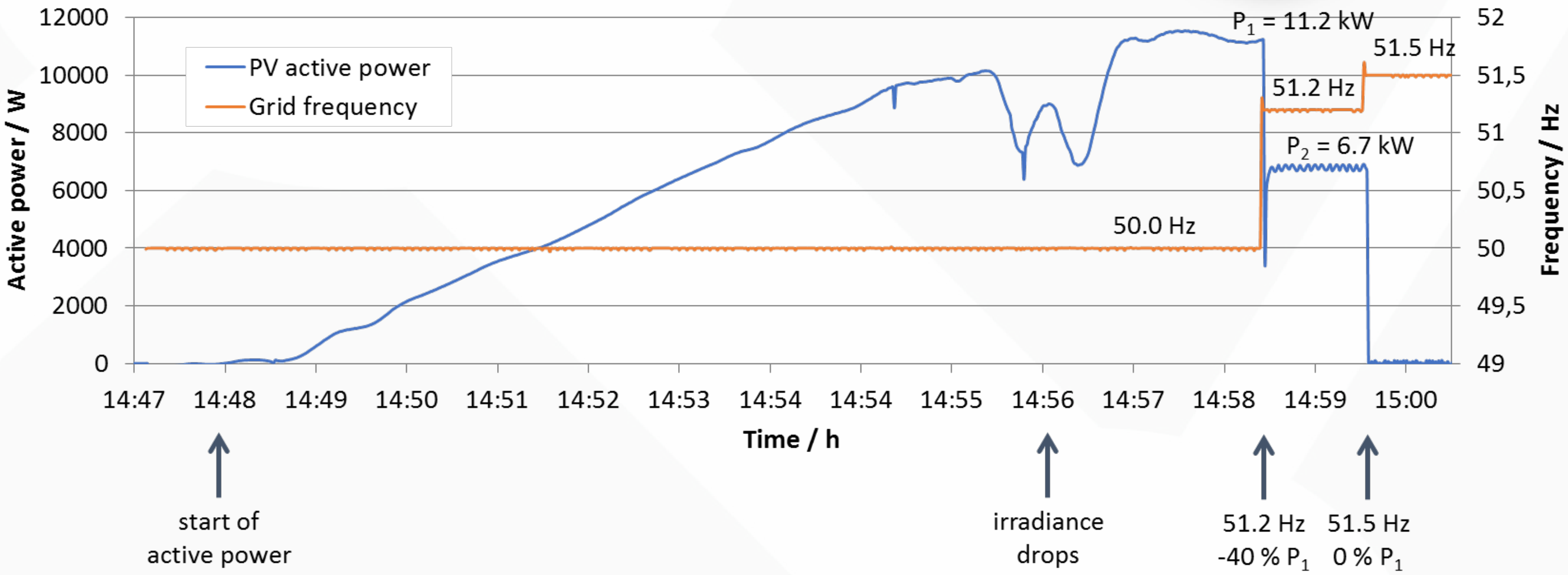
Validation of the Low Voltage Directive VDE AR 4105



optical fiber

AURORA

P,Q



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https://earthobservatory.nasa.gov/features/NightLights

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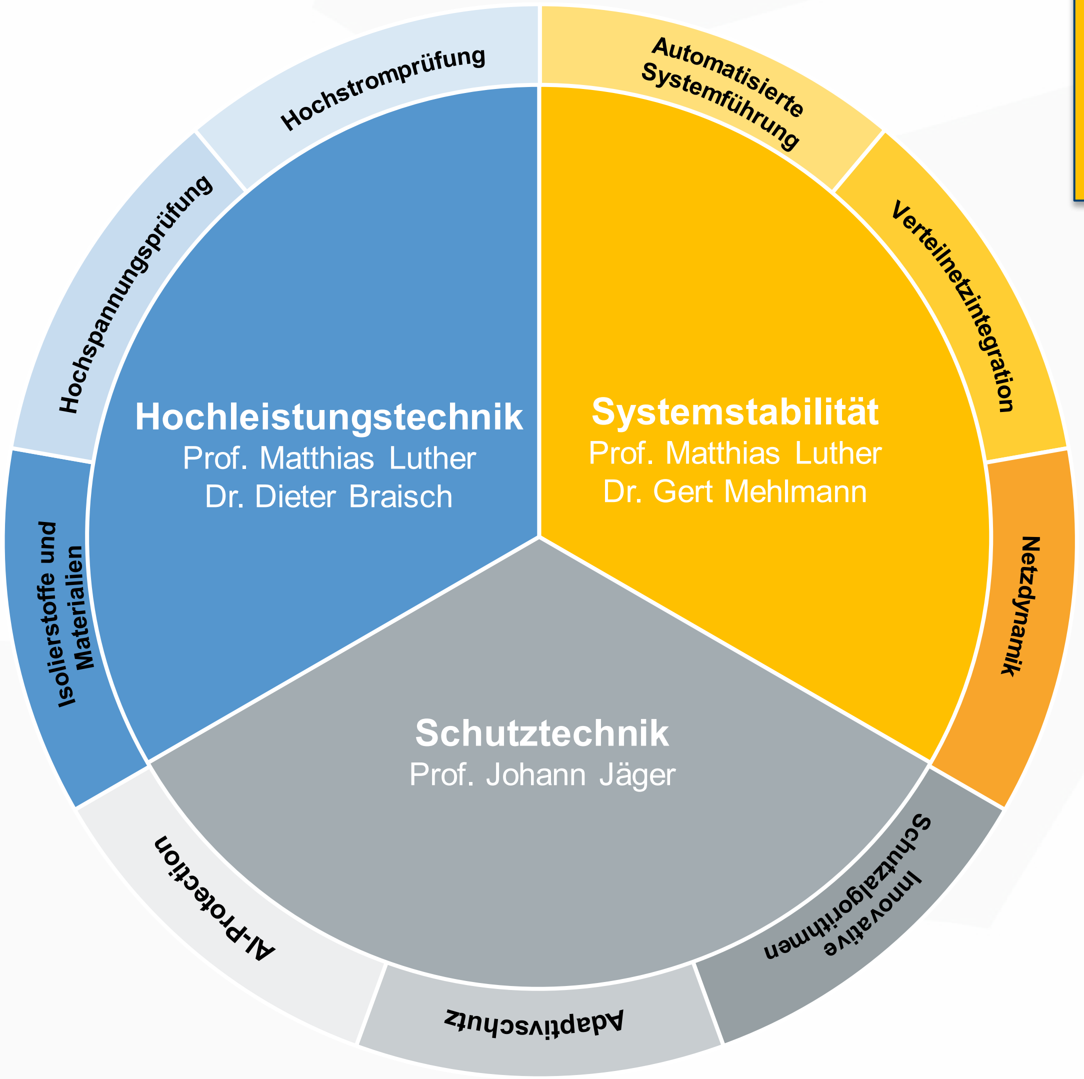
Forschungsschwerpunkte



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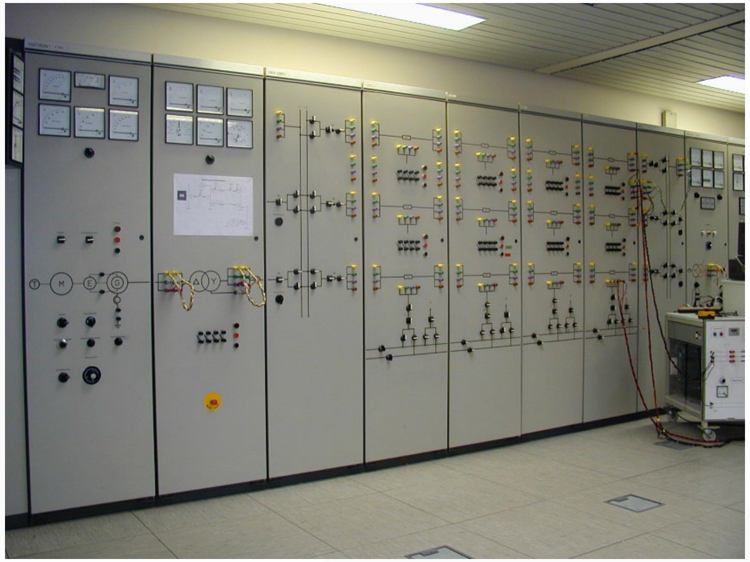
Laboratories for Power System Analysis

1975	1995	2019
Analogues System Model	Analogue Hybrid Simulator	Real Time Simulation Laboratory



- Power System Operation and Control
- Distance protection
- Digital motor protection

- Laboratory with measuring devices
- Analogue replication of a 12-pulse line-commutated HVDC system
- Analogue replication of a SVC (static var compensator)

- PHiL and HiL testing
- Digital twinning
- System integration and compliance analysis

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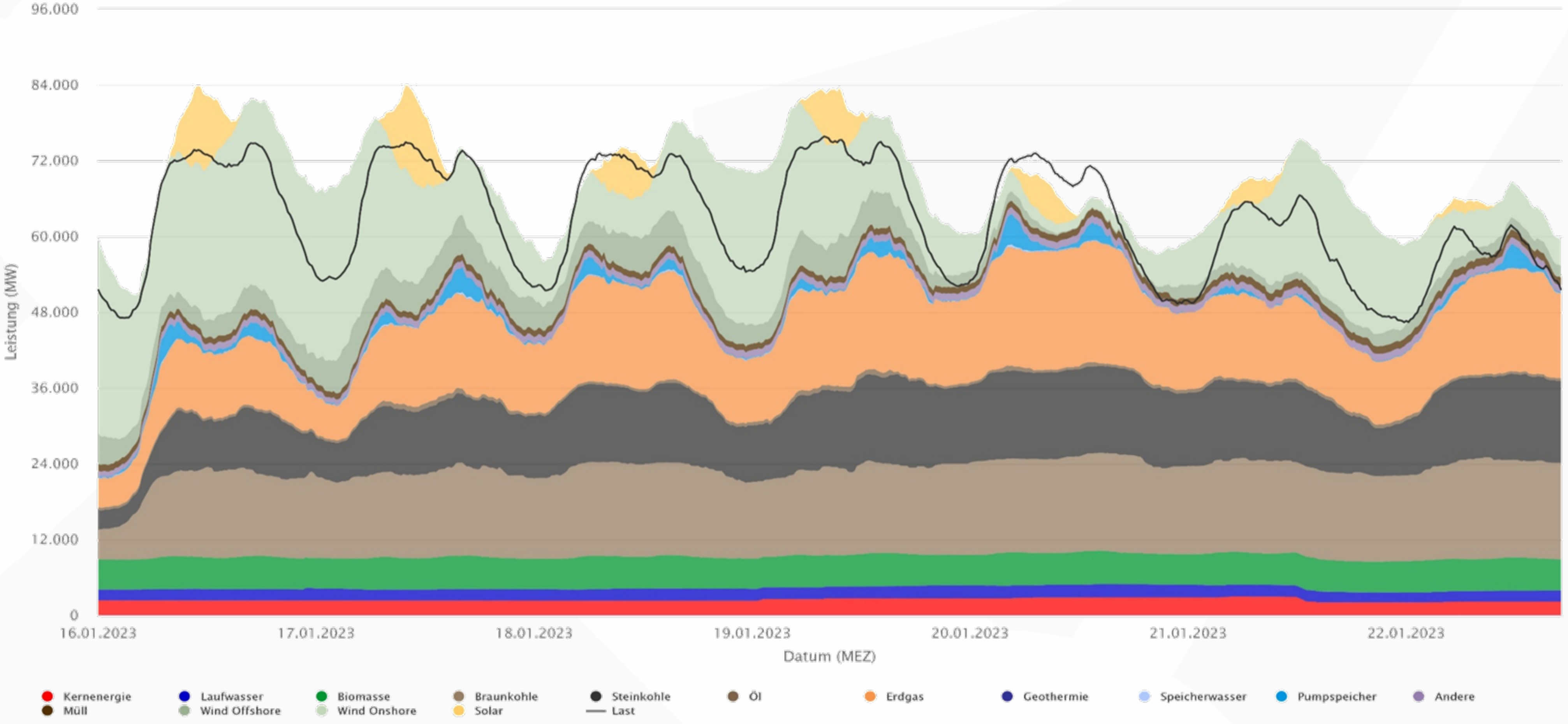
Generation and Consumption in Germany: Winter 2023

- Low PV infeed & Low Wind infeed



Source: Energy-Charts, Fraunhofer-Institut für Solare Energiesysteme

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Distribution Systems: network extension and digitilisation

Eine knackige Folie was es in den Verteilnetzen zu tun gibt !
Sektorenkopplung, Digitalisierung, … ggf Beispiel aus einem deutschen Verteilnetz

Haben wir dafür eine Grundlage?
David?

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An dieser Stelle eine Übergangfolien um von der Entwicklung der Netze zu den Stabilitätsthemen zu kommen.
Idee: Durch die Energiewende treten neue BM auf: Umrichter:

1. Folie Umrichtertechnologien: Grid Forming/Follwing
2. Dadurch Erweiterung der Stabilitätsbegriffe und Zeitbereiche
3. Dies erfordert neue Simulationswerkzeuge
4. Diese Werkzeuge ermögliche:
   1. Echtzeit-Cosimulation
   2. Echtzeitbetriebsführung
   3. Power-hardware in the loop uvm.
5. Conclusion

Im nachfolgen Abschnitt (ausgeblendet) haben wir dies einmal bespielhaft dargestellt.

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