# Empowering the Energy Transition: *The Crucial Role of Power Electronics for Power System Stability*

Dr. Hendrik Just

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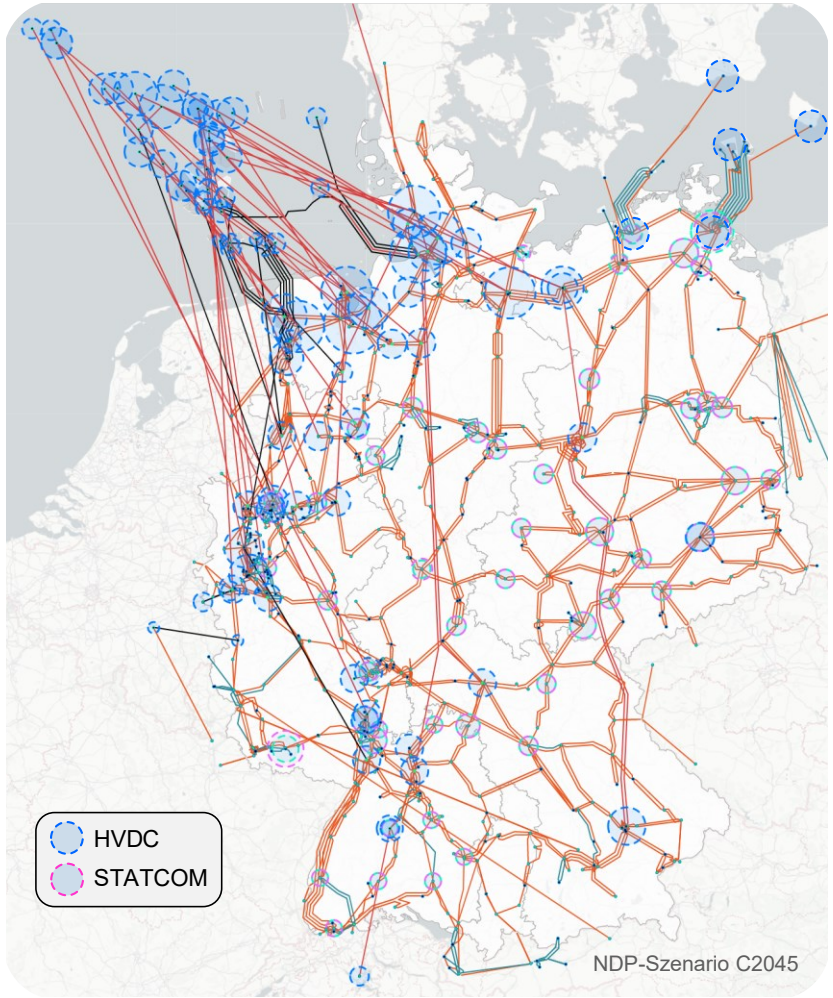
## *Sustainable Future*

### Increasing Electrification & Extensive Integration of Renewables

1. Displacement of conventional power plants by renewables
2. Growing demand of power transmission capability and efficient line utilization
3. Massive integration of large power electronic grid assets (e.g. Statcom)

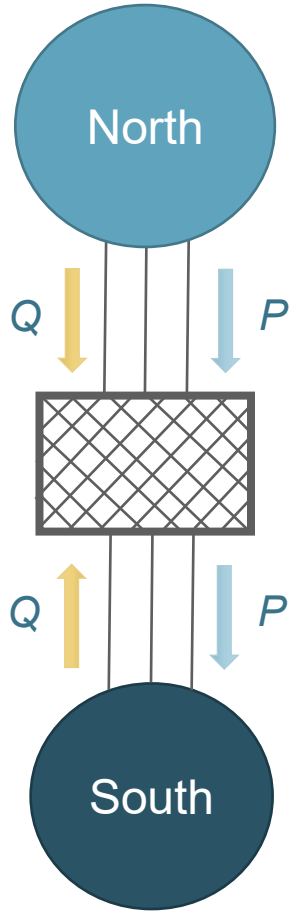
**Power Eletronics become the backbone of our Power System.**

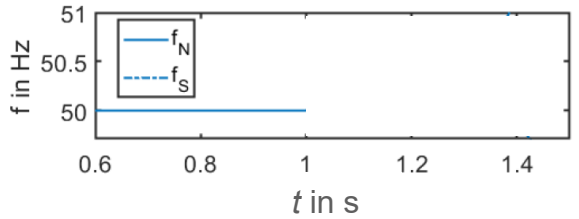


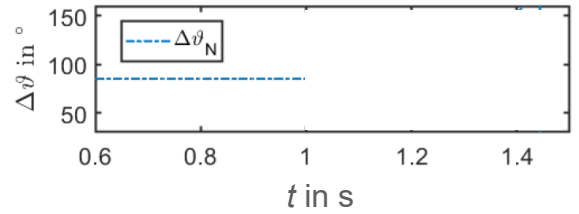
# *Growing demand of power transmission capability and efficient line utilization*

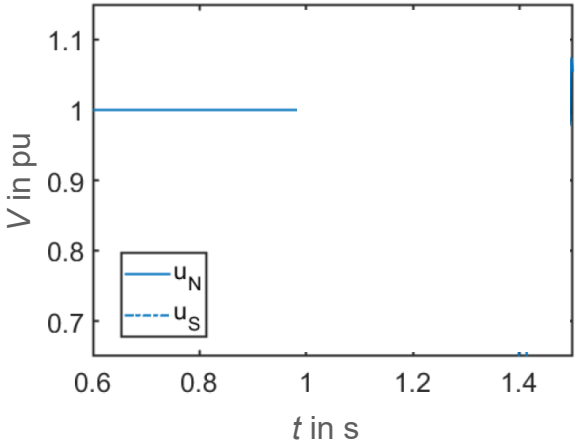
## Critical Contingencies in Future Power Systems

1. Initial state: high loaded / long distance transmission corridors
   - high power generation in North and high load in South
   - high capacitive reactive power demand
   - large initial angle deviations between North and South




[internal TSO Project]

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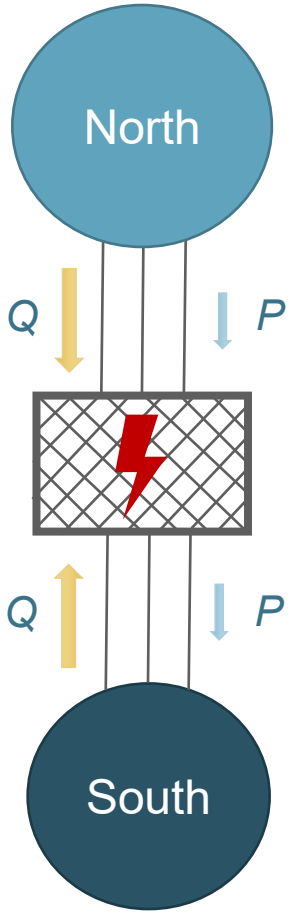
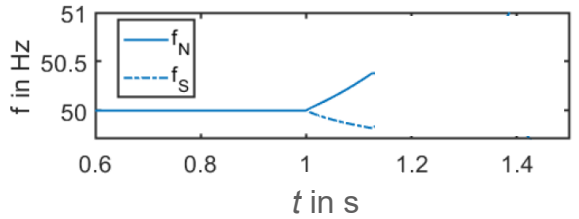
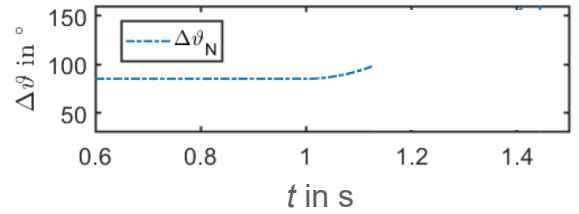
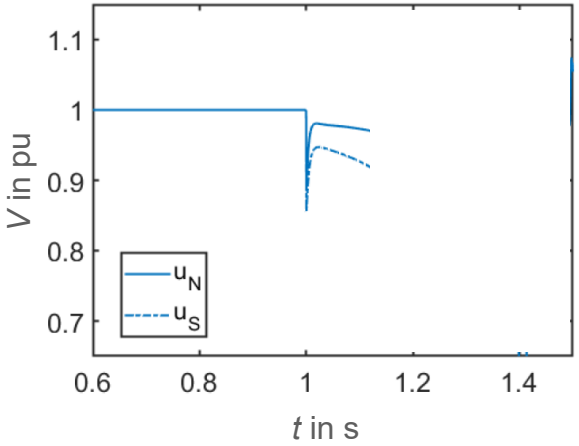
   - Significant decrease of power transmission capacity
   - North accelerates and South decelerates
   - Increasing angle differences and high fault current

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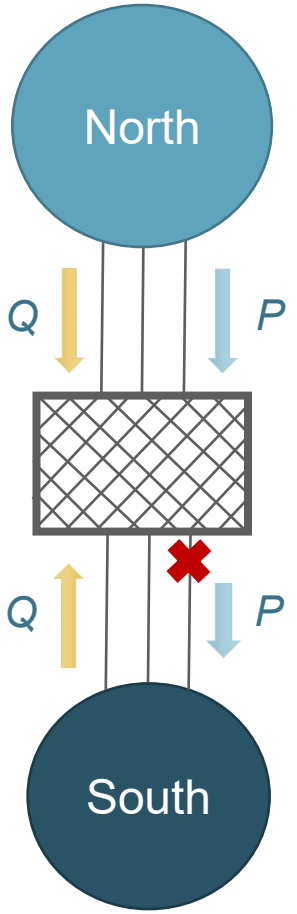
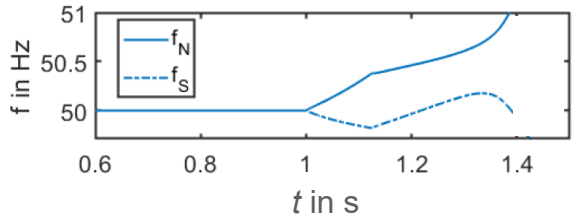
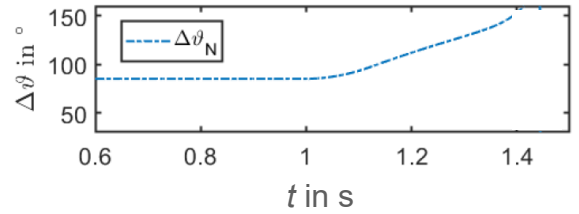
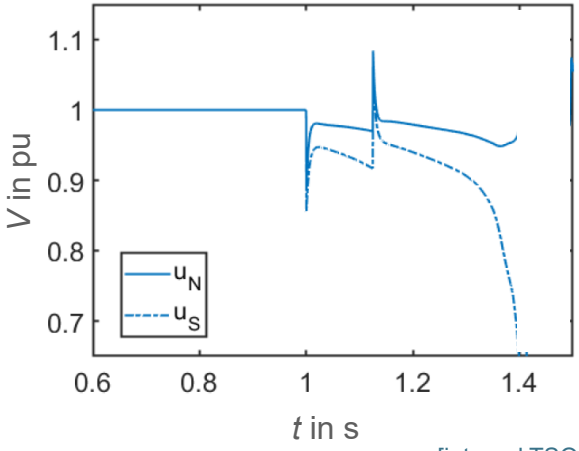
3. Critical Fault Clearance: tripping of transmission line
   - Power transmission reduction too large to resynchronize
   - Voltage recovery too slow to quickly increase power transmission capacity

**System Split between North and South**

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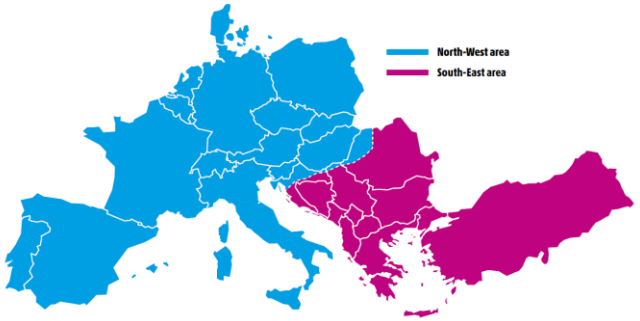
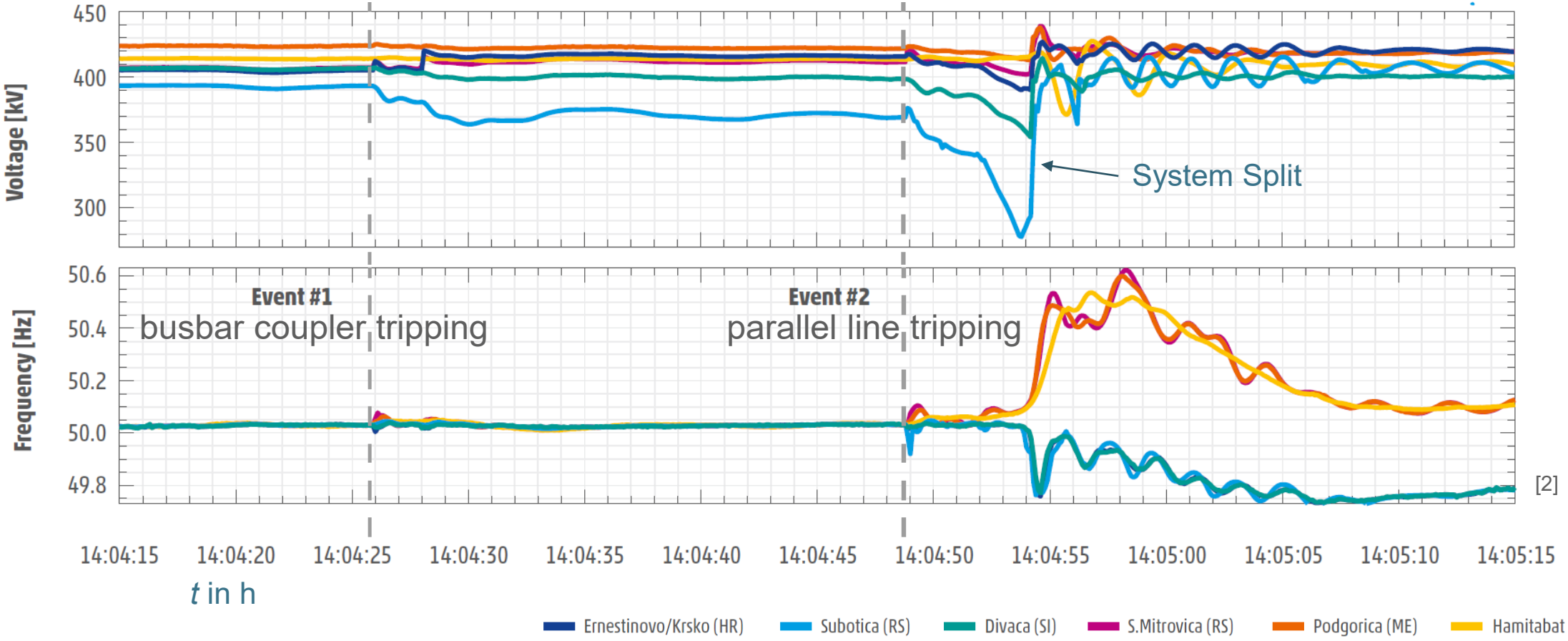
# System Split Scenarios - 08.01.2021 – Eastern Europe

## Stabilized and resynchronized!



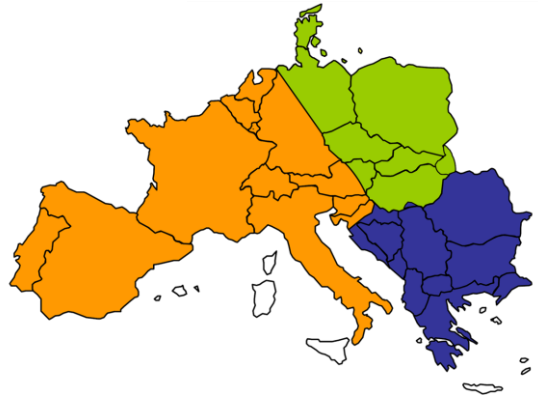




[2]

# Real System Split Scenarios

## Stabilized and resynchronized!

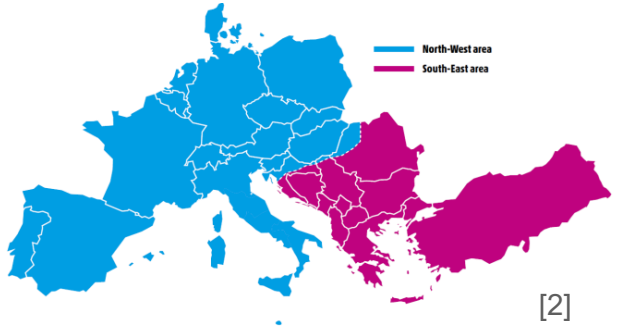
- 04.11.2006 – Central Europe



[1]

[1] ENTSO-E. *System Disturbance on 4 November 2006.* [Online]. Available: (Link).

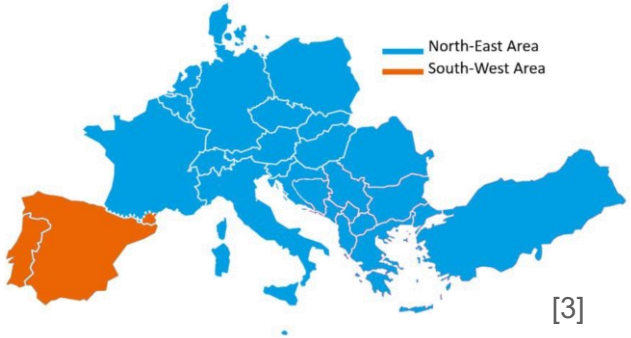
- 08.01.2021 – Eastern Europe




[2]

[2] ICS Investigation Expert Panel. *Continental Europe Synchronous Area Separation on 08 January 2021.* [Online]. Available: (Link).

- 24.07.2021 – Spain




[3]

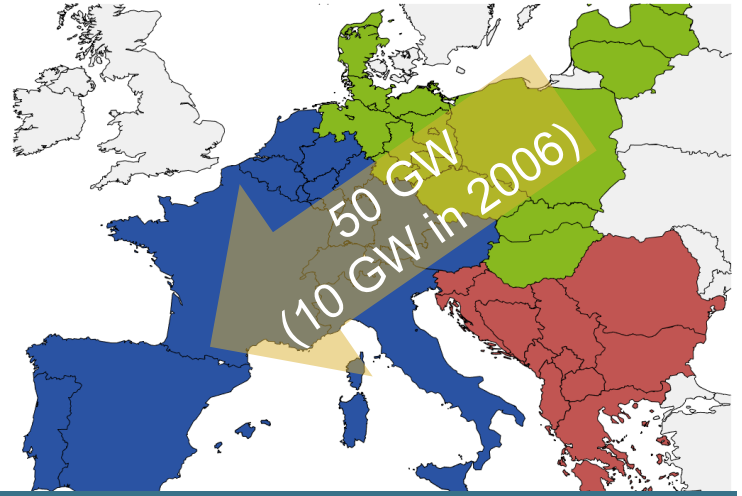
[3] ENTSO-E. *Continental Europe Synchronous Area Separation on 24 July 2021.* [Online]. Available: (Link).

# Future Trend – German Stability Reports

1. Growing demand of power transmission capability and efficient line utilization
2. Displacement of conventional power plants by renewables

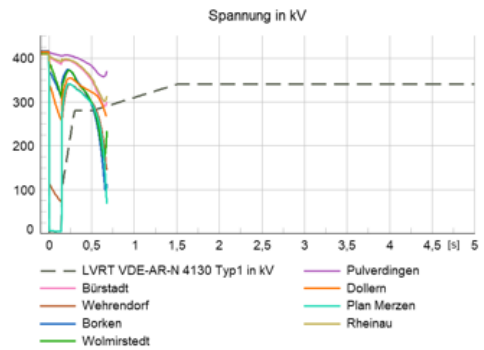
**Inertia and dynamic fault current**

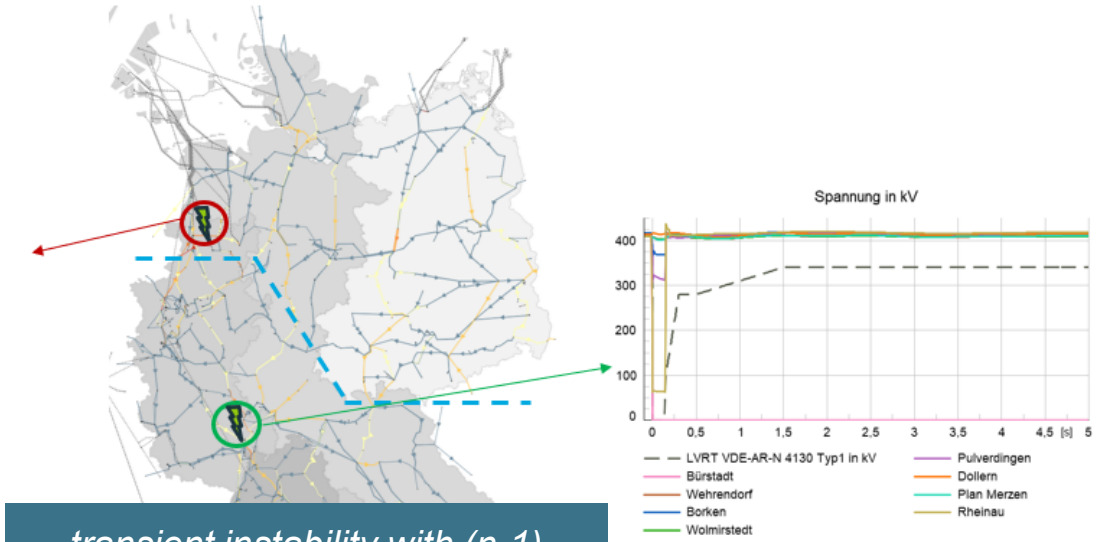
## Network Development Plan for 2037




*Exemplary system split of 2006 (transportation via interface in 2037)*

## Stability Report 2023 for 2030




*transient instability with (n-1) disturbances*

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# Covering the demand of instantaneous reserve

Today → 2025 → 2030

**1 Instantaneous reserve through TSO assets**

**Objective**: Acceleration of the state of technology using TSO pilots

- StatCom + Energy Storage
- Synchronous Condenser

**2 Market-based procurement**

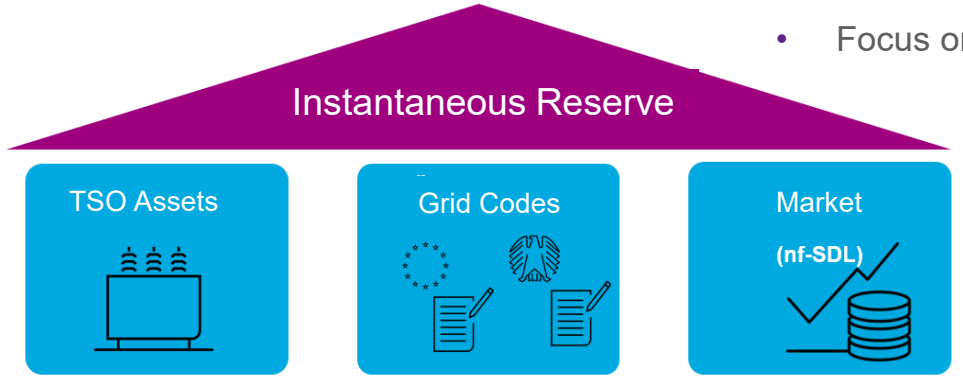
**Goal**: Accelerating the market maturity of customer systems with instantaneous reserve

- Implementation of a bonus system
- Focus on wind turbines and storage

**3 Minimum technical requirements**

**Target**: Contributions from all customer installations

- Further development of the technical grid connection guidelines
- Determination based on findings from market-based procurement

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Power System Stability

Transient Stability | Frequency Stability | Voltage Stability | Resonance Stability | Converter-driven Stability

1. Growing demand of power transmission capability and efficient line utilization

2. Displacement of conventional power plants by RES

?

– ***Grid-forming control*** to enable sufficient grid support of converter-based assets and generation units

– ***Extended ancillary services*** of all grid connectees (StatCom-Mode, Frequency Control,...)

– ***3 Pillars of Procurement:*** TSO Assets, Market, Grid Codes

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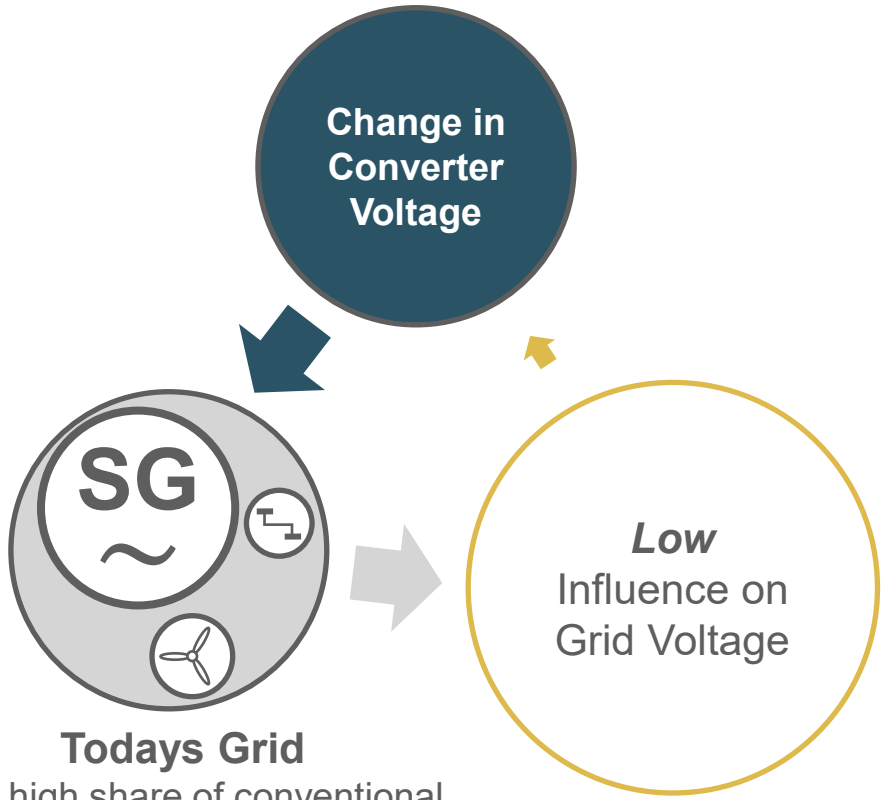
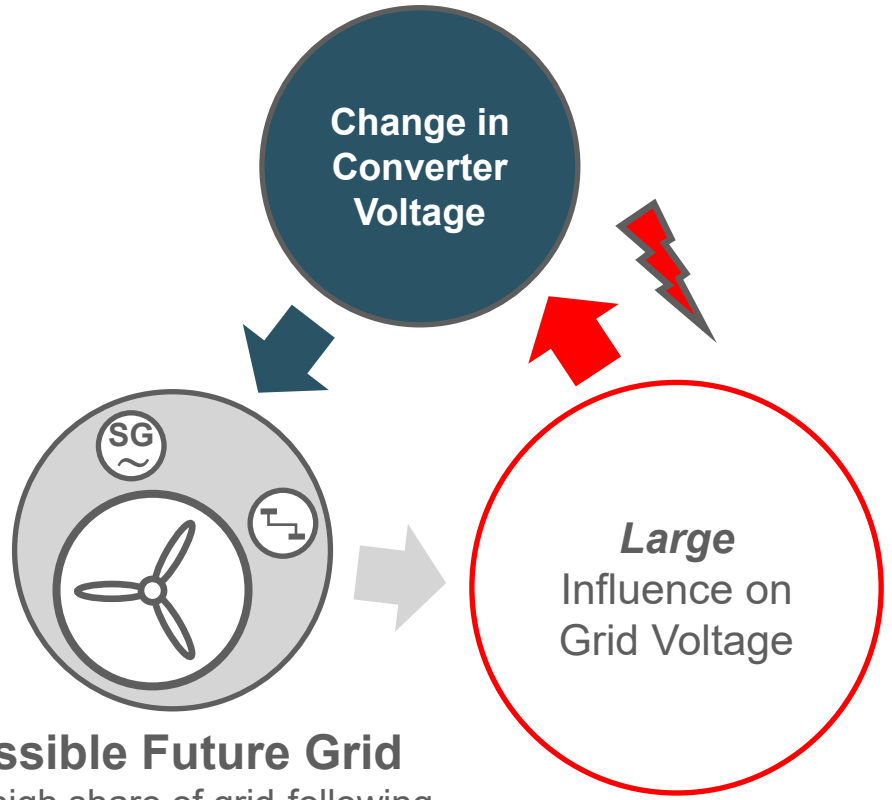
# Massive integration of large power electronic grid assets

## *Loss of Synchronism*




**Todays Grid**
with high share of conventional generators




**Possible Future Grid**
with high share of grid-following converters

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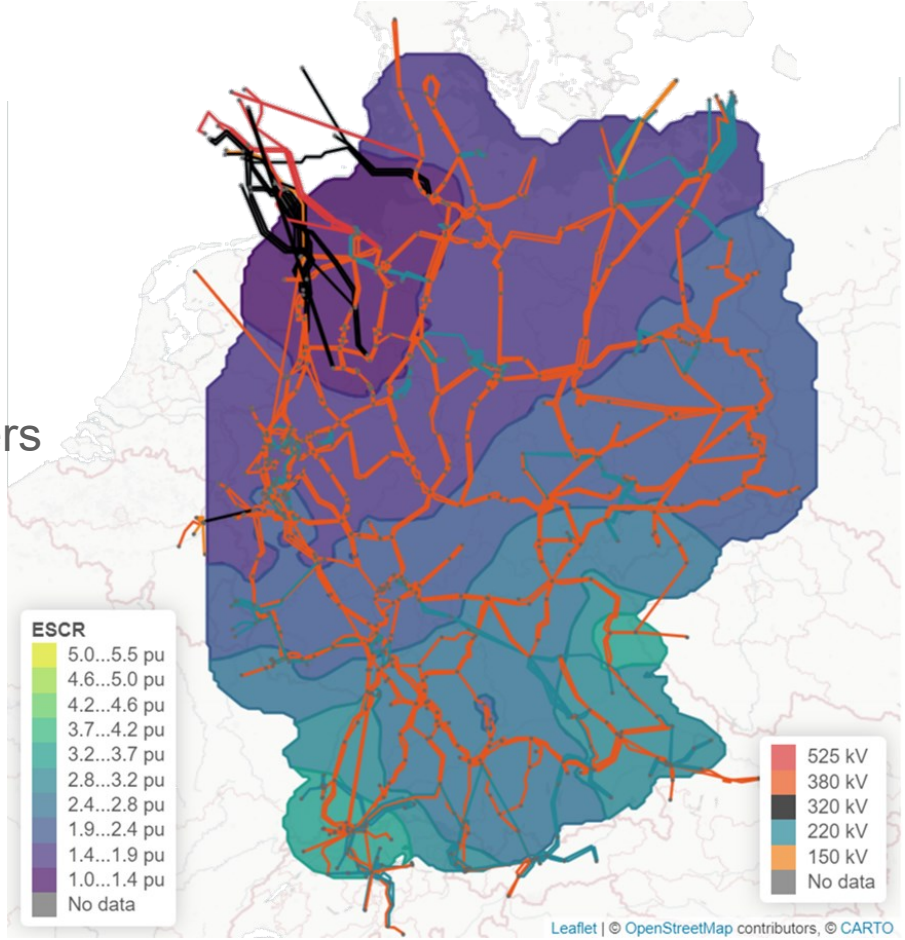
# Massive integration of large power electronic grid assets

## *Loss of Synchronism*

- Low system strength indicates potential instabilities of grid-following converters

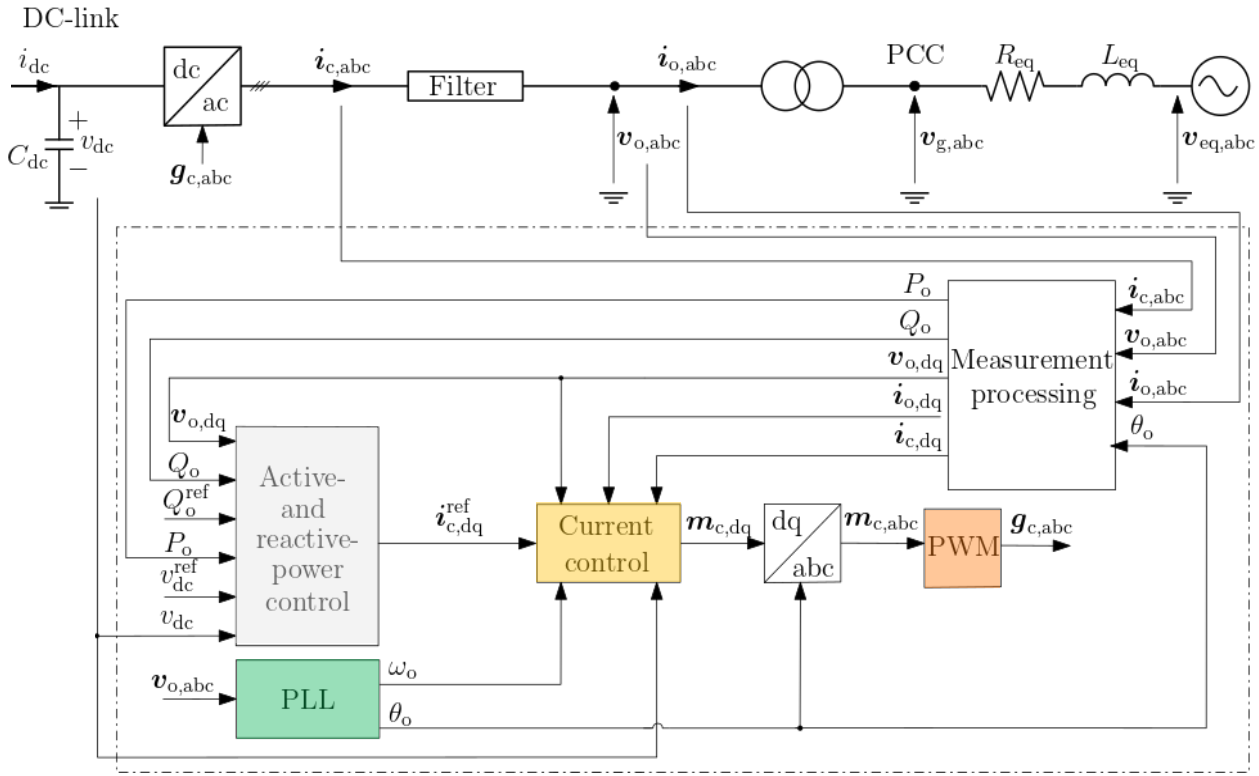
- Restrictions on the integration or operation of grid-following converters

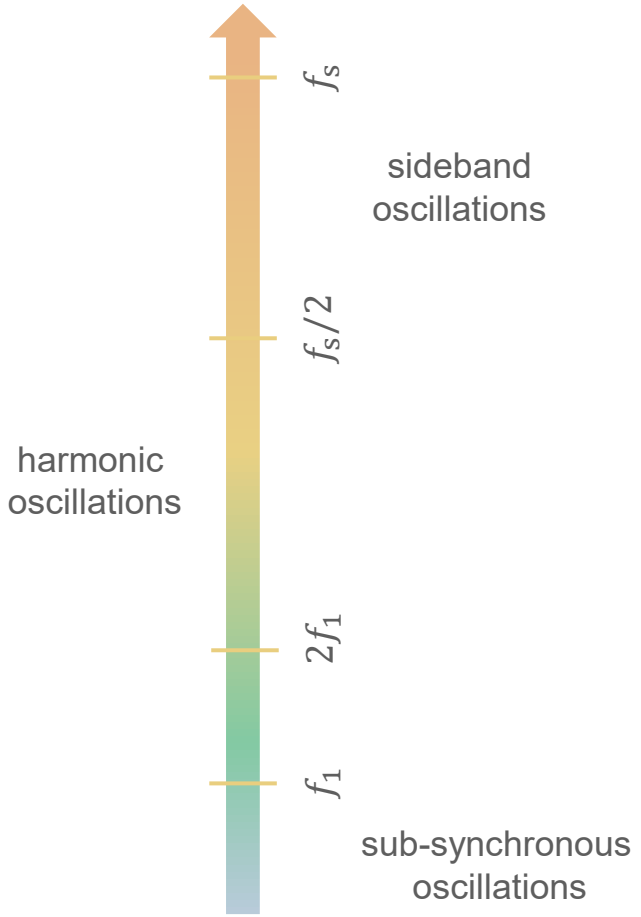
- ***Grid-forming converters:***
  - contribution to system strength
  - robustly operate under low ESCR conditions



# Massive integration of large power electronic grid assets

## *Control Interactions*




Definition: X. Wang, F. Blaabjerg, "Harmonic Stability in Power Electronic-Based Power Systems: Concept, Modeling, and Analysis," IEEE TRANSACTIONS ON SMART GRID, VOL. 10, NO. 3, 2019.

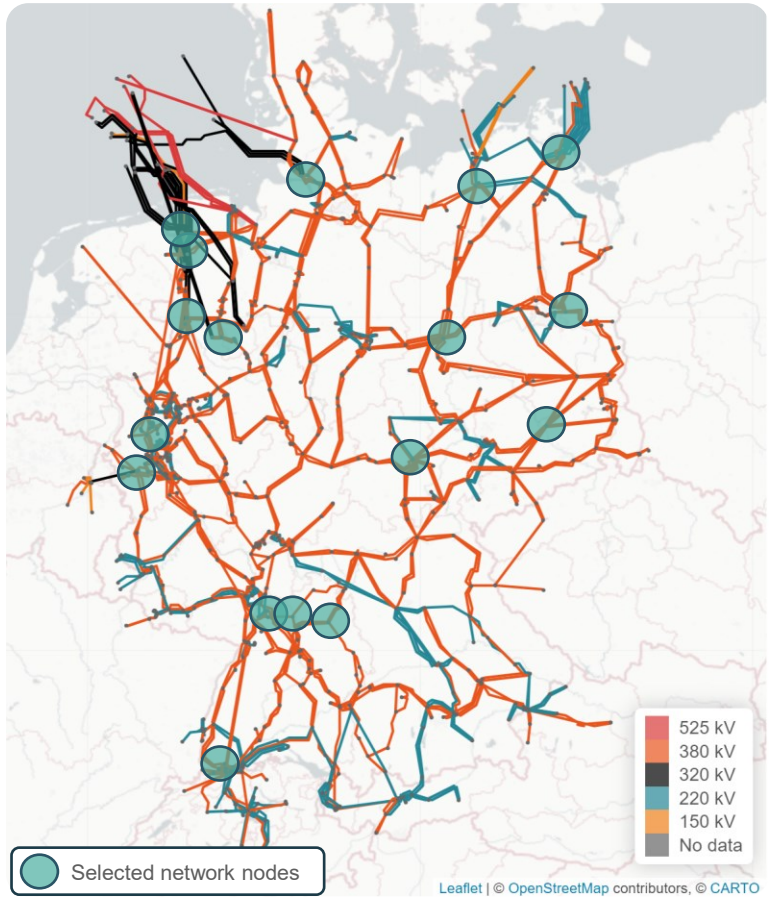
# Massive integration of large power electronic grid assets

## *Control Interactions*

- **Impedance-based stability criterion screening method** for identifying critical cases for control interactions

- **Harmonic stability can be confirmed** for the connection of further converter-based systems

- **Stability reserves may differ significantly** and may require detailed **EMT time-domain simulations**.



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Transient Stability | Frequency Stability | Voltage Stability | Resonance Stability | Converter-driven Stability

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- ***Extended ancillary services*** of all grid connectees (StatCom-Mode, Frequency Control,...)
- ***3 Pillars of Procurement:*** TSO Assets, Market, Grid Codes

1. Massive integration of large power electronic grid assets
2. Displacement of conventional power plants by RES

- ***Grid-forming control*** to reduce risk of control interactions and increase system strength
- ***EMT-dataset / simulation models*** to identify interactions and develop mitigation measures
- ***Modeling requirements for manufacturer models*** to ensure long-term compatibility

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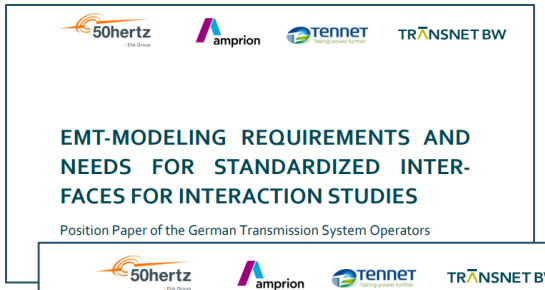
# Energy Sector-wide Commitment

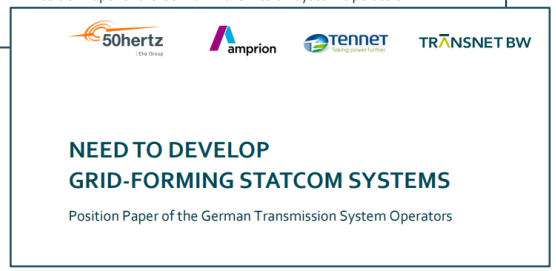
System Trends and Concepts

Research & Development

Regulations & Codes

Implementation

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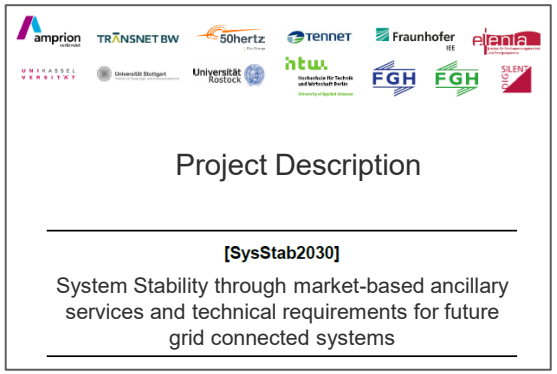


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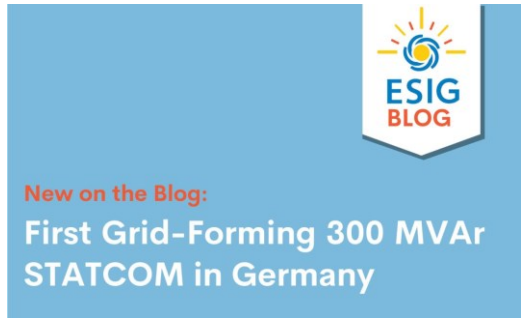


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timeline

# Energy Sector-wide Commitment

System Trends and Concepts

Joint Innovation

Research & Development

Regulations & Codes

Implementation

Parallelized Efforts

timeline

## Synchronized Goals

*between all Stakeholders including Research Community, OEM, TSO & Regulator*

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# Empowering the Energy Transition

## *The Crucial Role of Power Electronics for Power System Stability*

- ***Inertia & Fault current & Grid strength***: Optimized gridforming control for Wind, Batteries, PV and in future for all power electronic systems
- ***Monitoring & Prediction***: High-fidelity and tool-/compiler-independent EMT-Models, Grid-wide measurements & compliance monitoring, Dynamic Security Assessment
- ***Innovation, Implementation and Regulation***: Parallelizing Efforts and Joint Innovations of energy sector with all stakeholders!

***Make Power Electronics to the Key Enabler for a Sustainable Future!***

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Thank you