GRID INTEGRATION OF DISTRIBUTED GENERATION

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Renewable Energy Sources: Experiences in Germany

~40% share

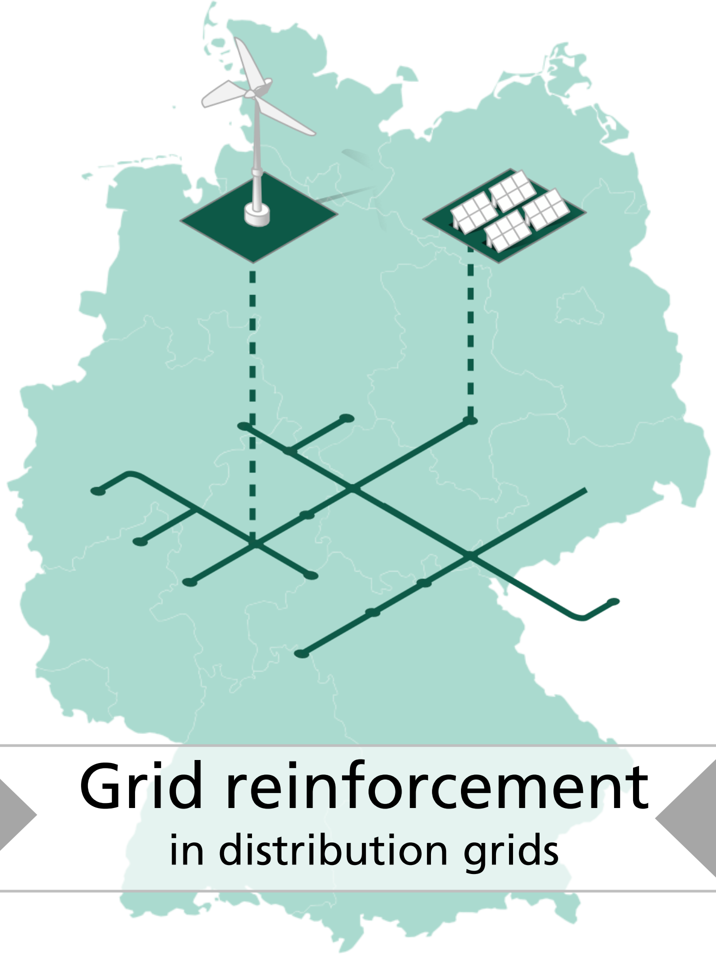
some regions >100 %

2050: 80-100%

>100 GWp RES

with 40-80 GW load between 0 % and 100 % of demand at diff. hours

2050: 400 GWp



~ 60 GW vRES distributed

in low and medium voltage grids

Grid reinforcement

in distribution grids

Generation > consumption

Reverse power flow is normal in many grids

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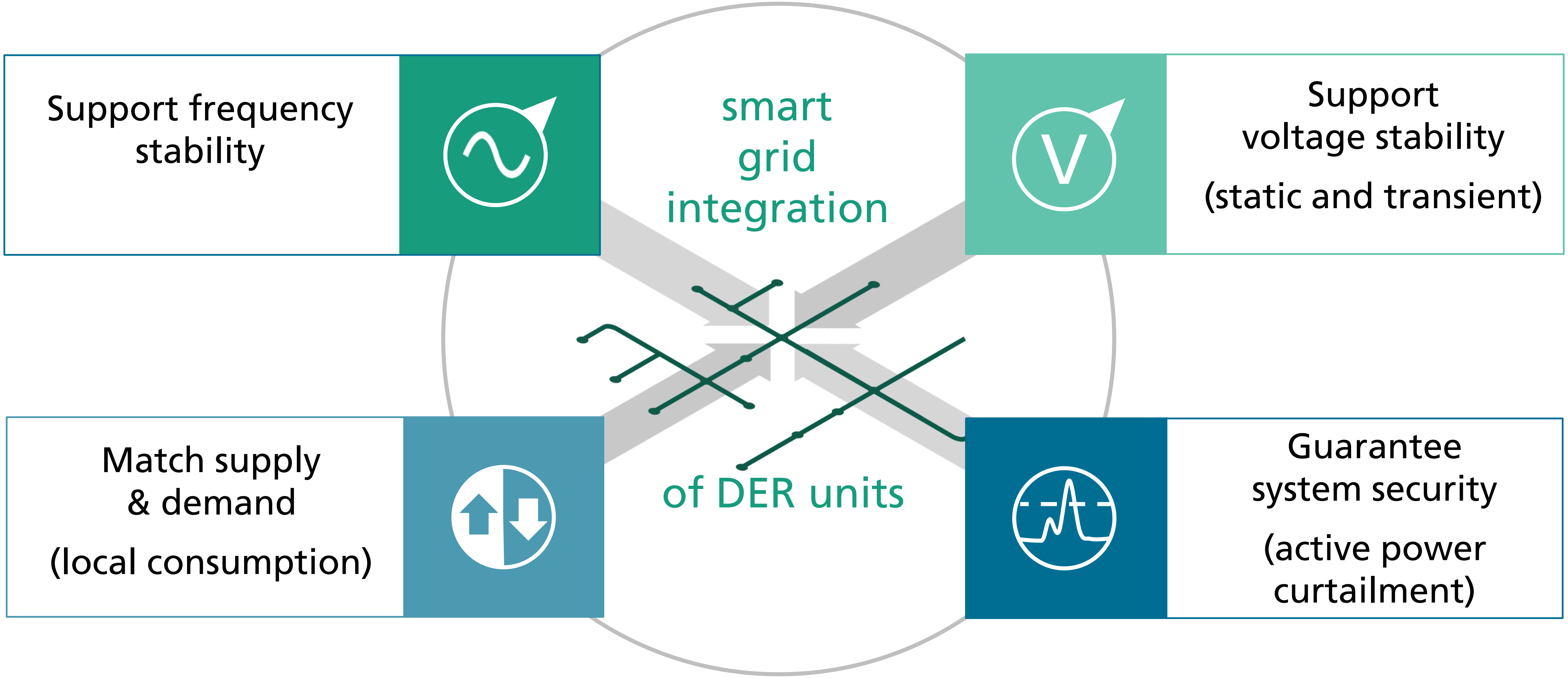
Outline

- **Smart Grid Integration of DER**
- Phase Model of vRE Integration

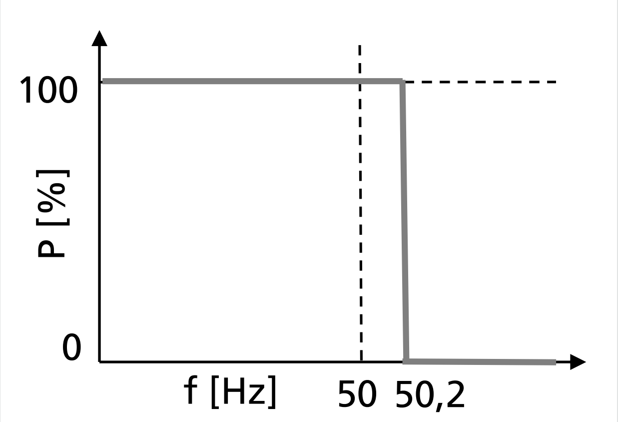
Smart Grid Integration of Distributed Energy Resources



Example: Frequency stability

PAST

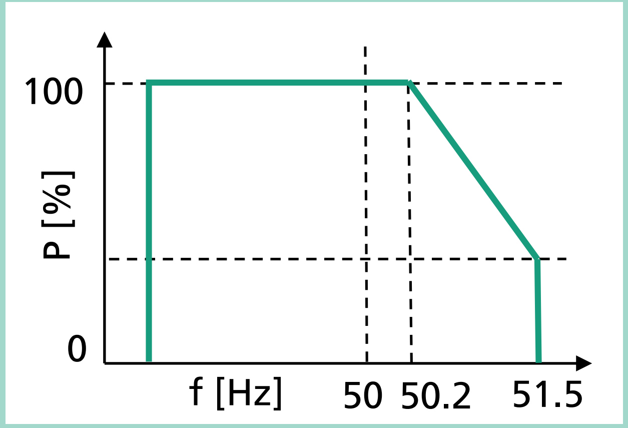
Underestimated PV systems impact on frequency



Disconnection at limit frequency:
Potential catalyst for system collapse

ACTIONS

Changes in grid code:
VDE-AR-N 4105 (2011)



Introduced droop: 50.2 → 51.5 Hz
(gradual power reduction)

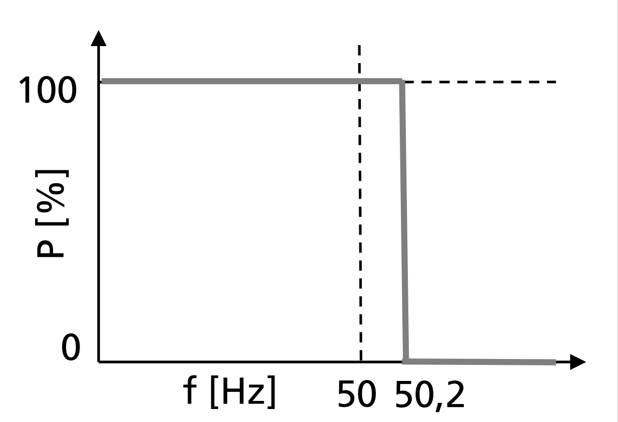
Retrofit of existing systems was necessary & costly

Source: VDE (2011)

Example: Frequency stability

PAST

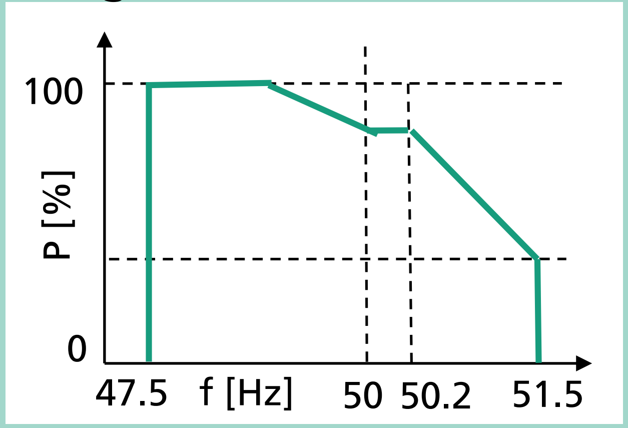
Underestimated PV systems impact on frequency



Disconnection at limit frequency: Potential catalyst for system collapse

ACTIONS

Latest Updates of grid codes for DG on all voltage levels, for controllable loads & for storage/EV-feed-in



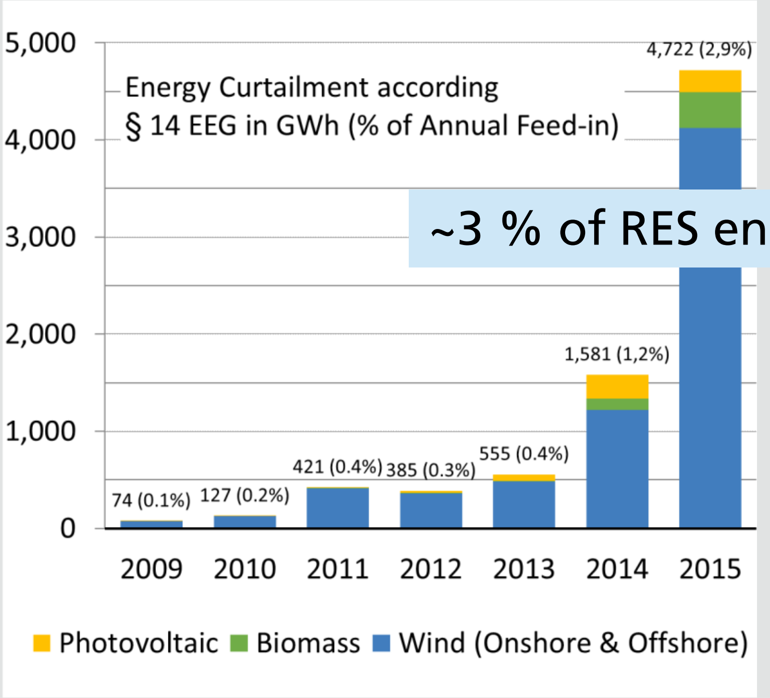
Capabilities for under- and over-frequency sensitive model
(depending on type and size of unit & power flow direction)

Source: VDE (2011)

Example: RES curtailment for congestion management

PRESENT

RES curtailment is increasing



~3 % of RES energy

82 % performed at DSO-level on TSO request:
Good TSO/DSO coordination needed!

TREND

RES curtailment also in network planning:

up to 3%

curtailment of annual RES feed-in allowed in order to avoid costs for grid reinforcement
(EnWG 2017 § 11)

After: German Federal Network Agency, EEG in Zahlen 2015

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Summary: Experiences in Germany

PRESENT

High DER penetration

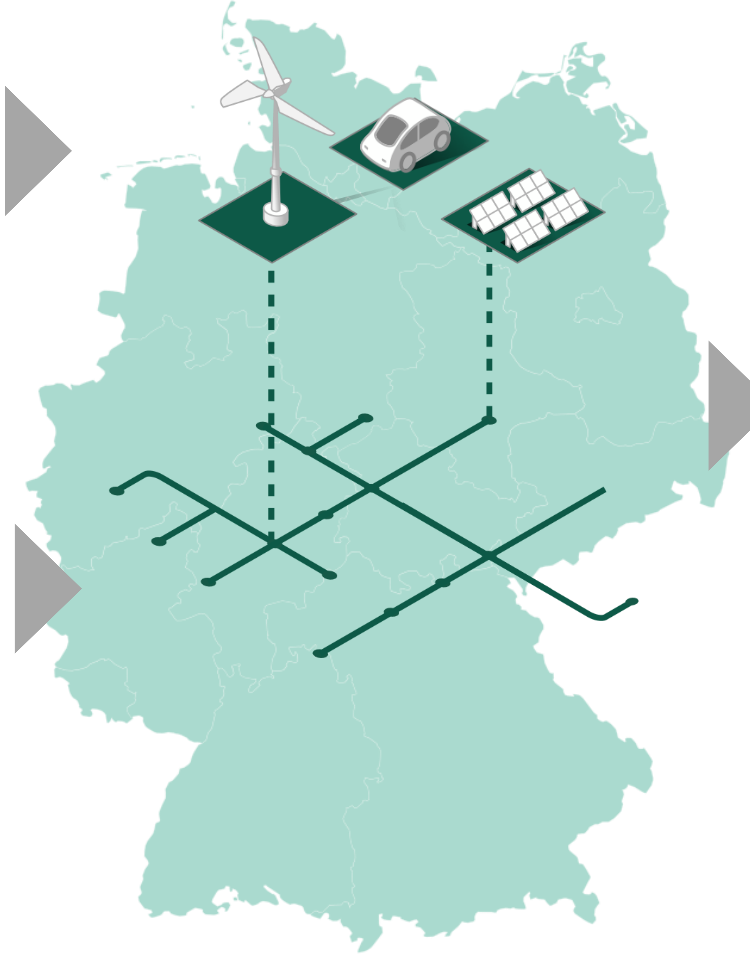
- further growth expected
- electromobility

GRID IMPACT

Increased and reversed power flows

Transmission and distribution grid need to be reinforced and extended:

- Time and costs



SMART INTEGRATION

- Harmonize integration for frequency stability
- Support voltage control for voltage stability and reduction of grid reinforcement
- Standardized control and communication interfaces
- Increase local consumption & reduce peaks

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Outline

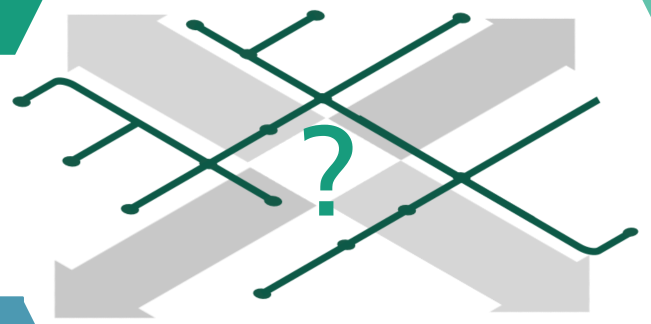
- Smart Grid Integration of DER
- **Phase Model of vRE Integration**

Smart grid integration of distributed energy resources: buzzwords

Future DSO

Grid modernisation

Smart grid



Active distribution system

DNO ▸ DSO 1.0 ▸ DSO 2.0

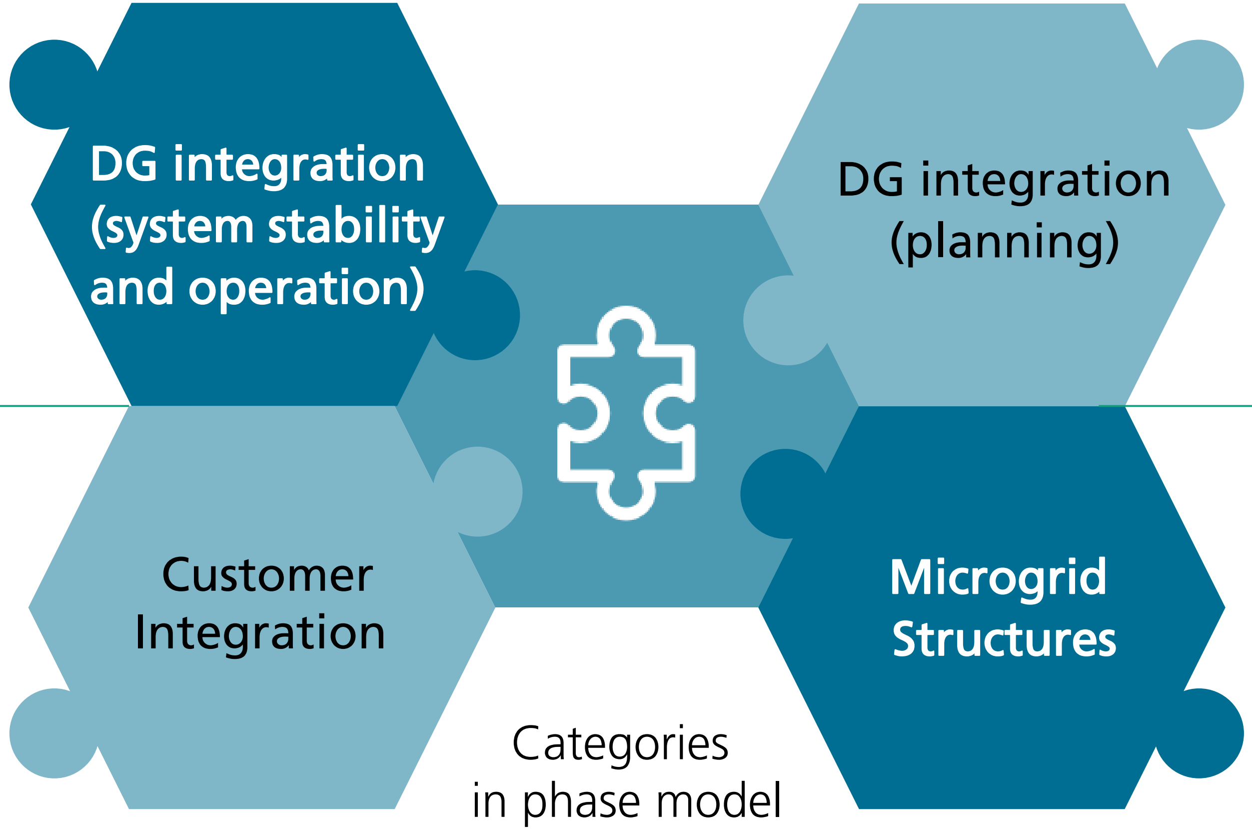
Bidirectional grids

Phase Model: from network operator to system operator
Four categories

- Grid Codes (control)
- Ancillary services (operation)

- Hosting capacity
- Grid reinforcement

Including customer storage/EV integration



Categories in phase model

Mega Trends

Decarbonization	RES
Decentralization	RES in distribution
01010 10010 10001 Digitalization	Data, information, communication, automation
Autarky	Cellular microgrid approach

Phase Model: DG integration (system stability)

from network operator to system operator

DG integration (system stability)

Decarbonization & Decentralization:
RES in distribution grids

PHASE 1: Guarantee system stability **with grid codes (plant readiness)**
Voltage, frequency, system security, protection, power quality

PHASE 2: Establish **DSO readiness with ICT / control center infrastructure**

PHASE 3: DSO with DER → system responsibility
Inverter-dominated grids require new control design (e.g. inertia control, voltage-controlled inverters, grid-forming inverters)
adaptive protection

Phase Model: DG integration (system operation)

from network operator to system operator

DG integration (system operation)

01010
10010
10001

Digitalization:
Data, information, communication, automation

PHASE 1: P,Q remote control including ICT (**plant readiness**)

PHASE 2: DMS/EMS **Control Center readiness** (on relevant voltage levels)
improve observability and controllability

PHASE 3:
Smart metering, smart grids, smart markets
DSO/TSO coordination
Full ancillary services functionality by RES/DER
Full observability and controllability → **automation, cyber-sec.**

Phase Model: DG integration (planning) 1/2

from network operator to system operator

DG integration (planning)

Decarbonization & Decentralization:
RES in distribution grids

PHASE 1: increase hosting capacity with voltage control
grid reinforcement if necessary!

PHASE 2: **increase cost-efficiency**
new components (e.g. OLTC transformers)
P-curtailment
massive grid reinforcement in certain areas

PHASE 3: **further increase cost-efficiency**
integrate P/Q flexibilities

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Phase Model: DG integration (planning) 2/2

from network operator to system operator

DG integration (planning)

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10010
10001

Digitalization:
Data, information, communication, automation

PHASE 1: worst-case planning

PHASE 2: increase cost efficiency with **improve planning capabilities:**
Digitalization of grid data, update planning rules,
include operation → **New planning tools**

PHASE 3: observability & automation → operating at physical limit
regional markets for flexibilities
automized planning procedures & uncertainty containment

Phase Model: Customer Integration (Storage / EV) 1/2

from network operator to system operator

Customer Integration (Storage / EV)

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10010
10001

Digitalization:
Data, information, communication, automation

Drivers for Smart Homes:

- Digitalisation trend
- technological-oriented customers
- Etc.

Drivers for Smart Meters:

- Reduce non-technical losses (upgrade meter infrastructure)
- Observability of changed customer behavior!
- Controllability of customers (payment culture, voltage checkups etc.)
- Future business models
- etc.

Phase Model: Customer Integration (Storage / EV) 2/2

from network operator to system operator

Customer Integration (Storage / EV)

Decarbonization & Decentralization:
RES in distribution grids

PHASE 1:
Drivers for storage/EV: **customers have it**
energy efficiency in transport and heating/cooling (EV, HP, CHP)
net metering (business model for controllable loads and storage)
incentives schemes

PHASE 2:
grid codes for storage / EV

PHASE 3:
active storage integration
energy management / response schemes
increase system flexibility → to guarantee energy balance

Phase Model: Microgrid Structures

from network operator to system operator

Microgrid Structures

Autarky (Island Grids / Microgrids)

(Island grids if interconnection too expensive)

PHASE 1: grid codes / system design for island grids

Drivers for microgrids: reliability or autarky

PHASE 2: grid codes for microgrids

automation

PHASE 3: Resilient cellular system designs

- Distributed automation
- Planning tools

Conclusions on Phases of DER Grid Integration

- Phase 1 (vRE integration started):
  grid reinforcement / extension where needed
  plant control readiness → **grid codes!**

- Phase 2 (significant vRE penetration in certain distribution grids):
  DSO readiness: **planning & operation with large-scale vRE**

- Phase 3 (significant vRE penetration throughout distribution grids and on national scale in transmission):
  DSO with significantly increased system responsibility:
  all ancillary services also by vRE, storage, electrical vehicles, controllable loads
  new control design (low-inertia inverter-dominated grids)
  DSO/TSO+ coordination
  automation & cyber security

- Increased reliability and resilience in **microgrid structures** possible (Phase 3)
  dependent on design, cyber-security, cost-efficiency, requirements for improved reliability or resilience, ...

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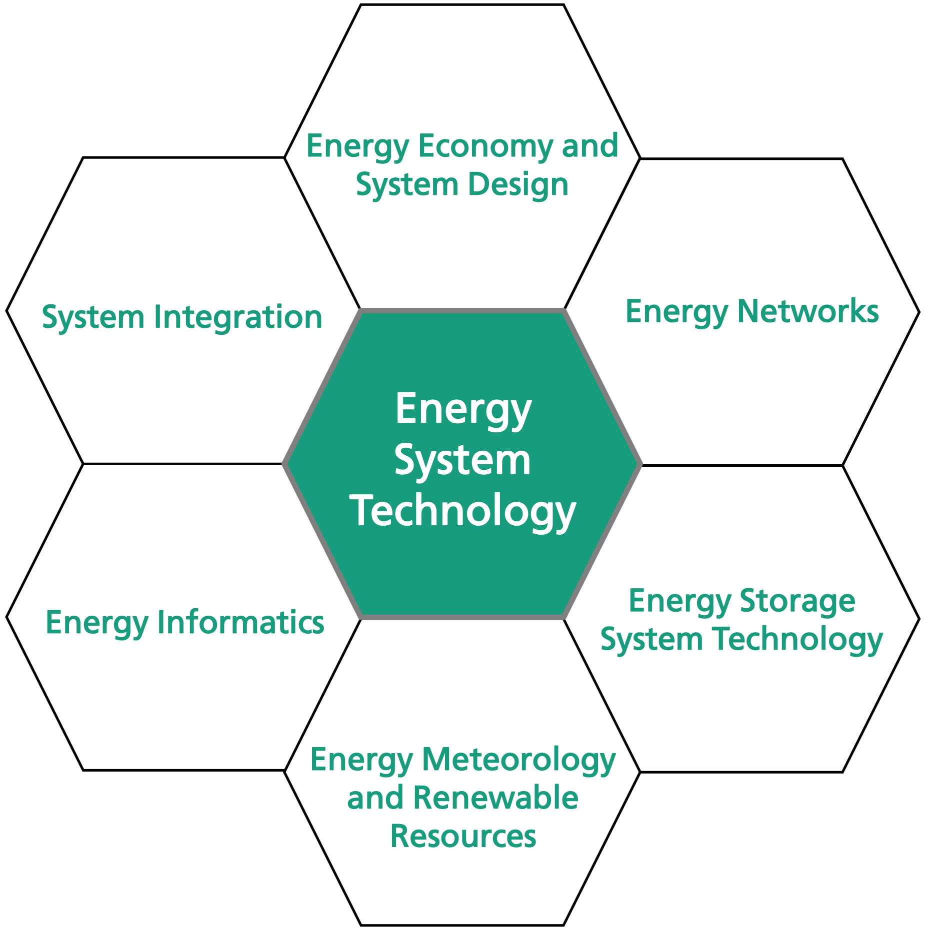
Energy System Technology to realize the 'Energiewende'



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Department e²n

Energy Management and Power System Operation

- Development of models, methods, algorithms and tools for analysis, operation and control, and design of the future decentralized power system with high share of renewable energies. e.g. www.pandapower.org
- Multi-Objective/Perspective/Level Optimisation of the power system
- Simulation of the power system over time scales and system levels.
- Resilient Control Design incl. power system stability, network restoration, microgrid structures