TECHNISCHE UNIVERSITÄT DRESDEN

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EE²

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Reactive power provision from the distribution grid and its effects on redispatch cost

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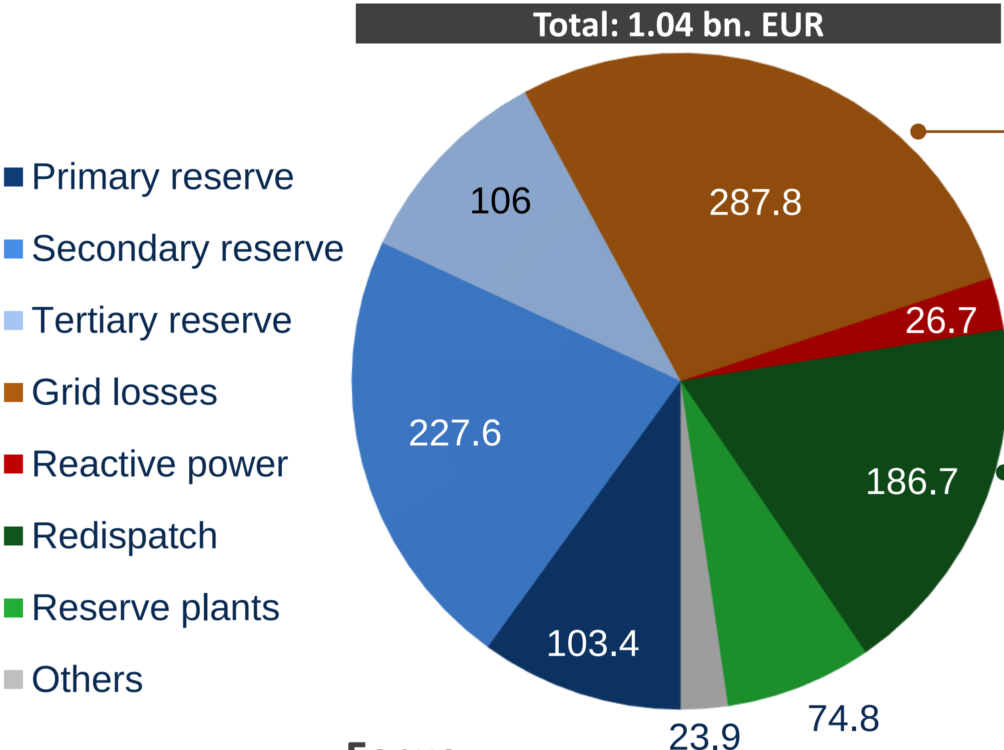
Reactive power provision from the distribution grid and its effects on redispatch cost

Reactive power influences the cost of various ancillary services

Cost of ancillary services Germany 2014, in mio. EUR; redispatch measures in GWh



Losses caused by real and reactive power transfers

Direct payments for reactive power services

Current- and voltage-induced redispatch

Control area	Current [GWh]	Voltage [Gwh]
TenneT	581	232
50Hertz	1751	-
TransnetBW	16	-
Amprion	20	-

Focus

Additionally: ~180 mio. EUR curtailment cost

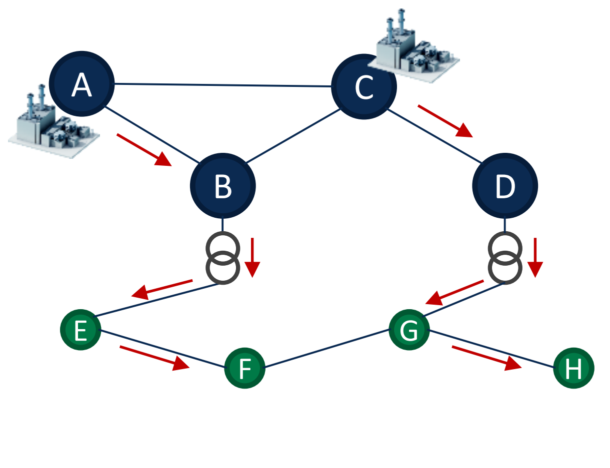
How does reactive power provision influence redispatch / curtailment cost ?

Source: Bundesnetzagentur 2015

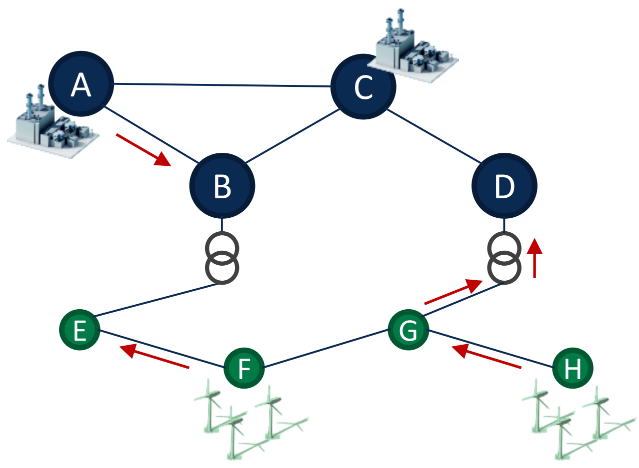
Quality of reactive power provision can be improved by 110kV grids

Comparison of reactive power supply with and without 110 kV grids

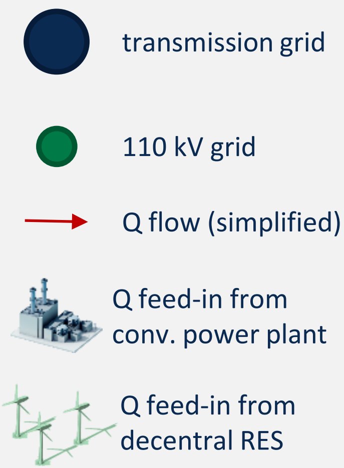
Conventional reactive power supply



Reactive power from 110kV grids



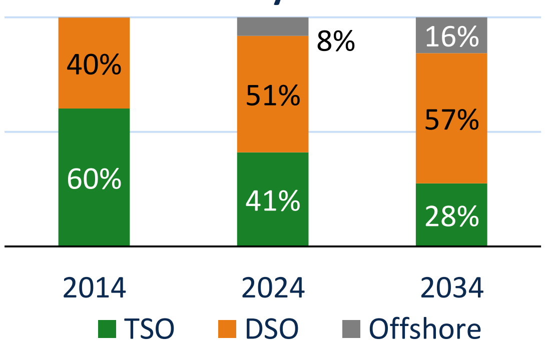
Legend



- Reactive power required to **compensate behavior of electricity lines** and to ensure **voltage stability**
- Historically, reactive power is supplied by **large conventional power plants** mainly in the transmission grid
- Distribution grid connected **RES are capable** of reactive power provision
- Reactive power can be **supplied locally** and availability can be increased

→ **Reactive power supply from distribution grids should be fostered**

Electricity feed-in



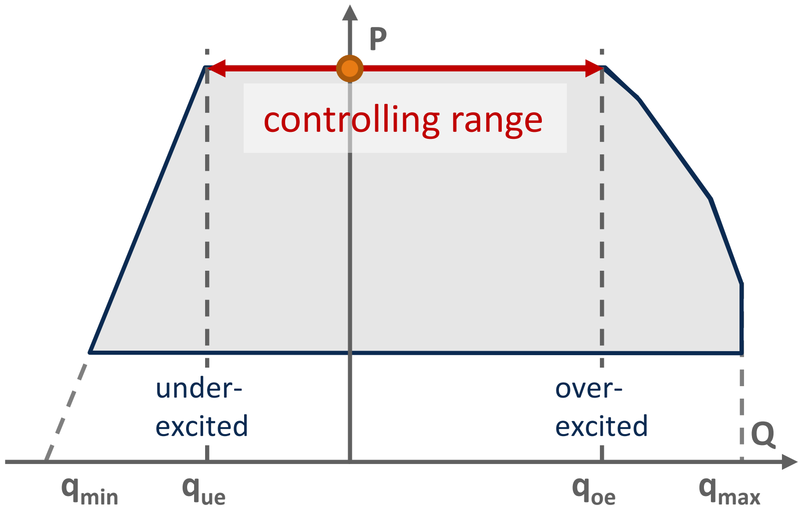
Source: Kraftwerksliste Bundesnetzagentur 2015, Netzentwicklungsplan 2015

Reactive power provision from the distribution grid and its effects on redispatch cost

Reduction of real power generation leads to opportunity losses

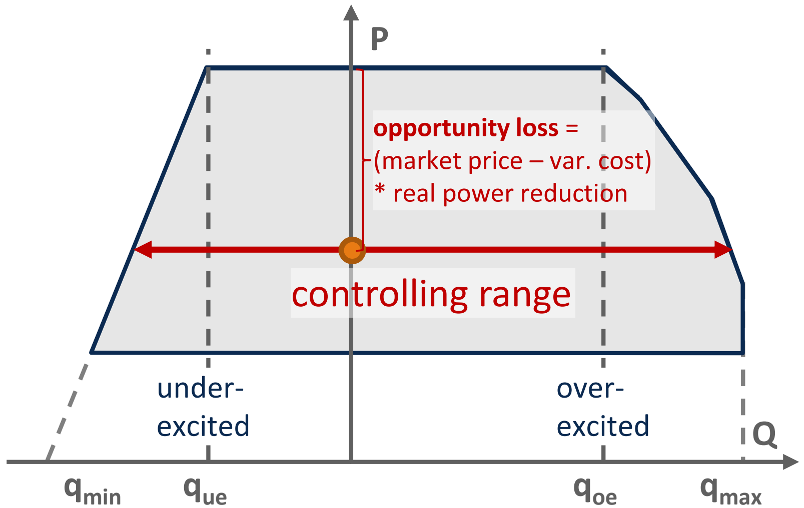
Generator capability curves

Scheduled full load operation



- Provision and consumption of **reactive power** between q_{ue} und q_{oe} **with no additional cost** (not taking into account internal losses)

Reduction of real power



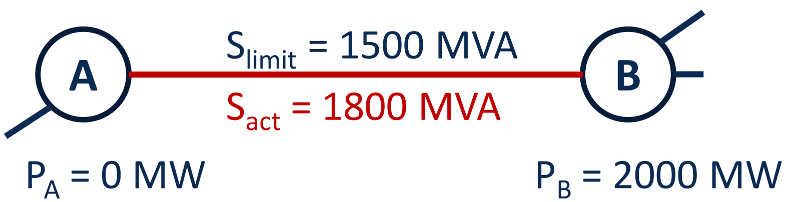
- **Reduction of real power** (i.e. through voltage-induced redispatch)
- **Opportunity loss** through additional provision or consumption of reactive power between q_{min} and q_{max}

Redispatch measures can be conducted because of current or voltage violations

Example: current- vs. voltage-induced redispatch

Violation of current limits

- Power plant dispatch (as market result) causes overload of a transmission line

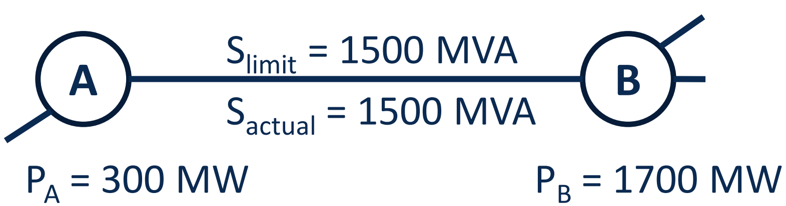


Violation of voltage limits

- Power plant dispatch (as market result) causes a violation of voltage limits

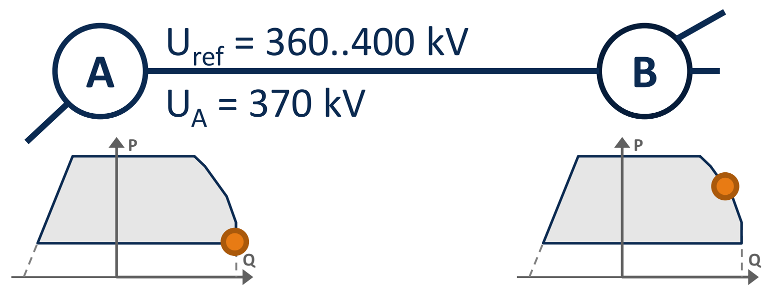
Current-induced redispatch

- Decrease of real power generation at one side of the congestion
- Increase on the other side



Voltage-induced redispatch

- Adjustment of real power generation in order to increase reactive power provision



Reactive power provision from the distribution grid and its effects on redispatch cost

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Two scenarios with and without reactive power provision from wind turbines compared

Scenarios to be compared

Redispatch & curtailment cost
- Current-induced
- Voltage-induced

Scenario Conv

Conventional reactive power supply

- Large conventional power plants connected to the transmission and 110 kV grid supply reactive power
- No reactive power supply of decentralized RES

Comparison

Scenario Q feed-up

Reactive power feed-up from the 110 kV grid

- Reactive power supply of transmission and 110 kV grid connected power plants
- Reactive power supply by wind farms connected to the 110 kV based on grid code requirements

Comparison of 4x4 typical grid situations:
- Wind feed-in
- Residual load

Classified as
- **L**ow
- **M**iddle
- **H**igh
- **V**ery High

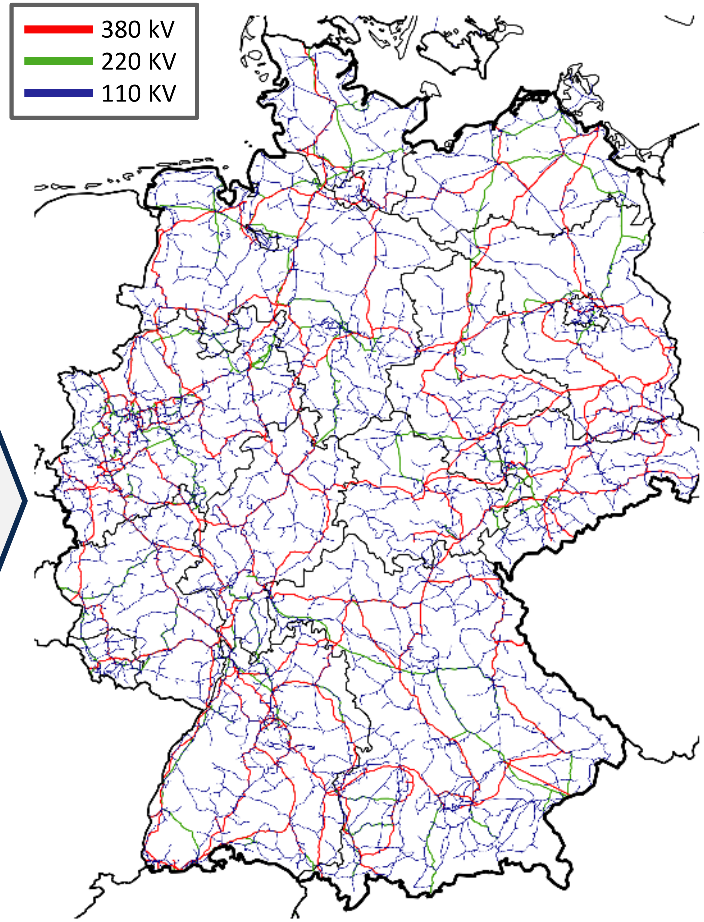
110kV grid model of Germany developed based on Open Street Map data

High resolution 110kV grid model

OSM data

- Substations
  380 / 220 / 110 kV
- Transmission lines
  380 / 220 / 110 kV

- **Nodes** with generation / load
- **Auxiliary nodes** (for intersections)
- **Lines** with from/to properties and technical parameters
- **Transformers** between transmission and distribution grid



Power plants & RES

Attribution to nodes

- **Power plants:** based on geographical coordinates
- **RES:** based on zip codes of installation

Load

- Attribution based on population / GDP of the surrounding administrative unit

Nodes: 5708
Lines: 6460
Transformers: 367

Redispatch cost calculated in a 3-step approach

Model approach

Step 1
Market model

- **Electricity market model** (copper plate) for Germany and neighboring countries to generate **power plant dispatch**
- **NTC-based** trade between market zones
- Only **real power** (P) dispatch

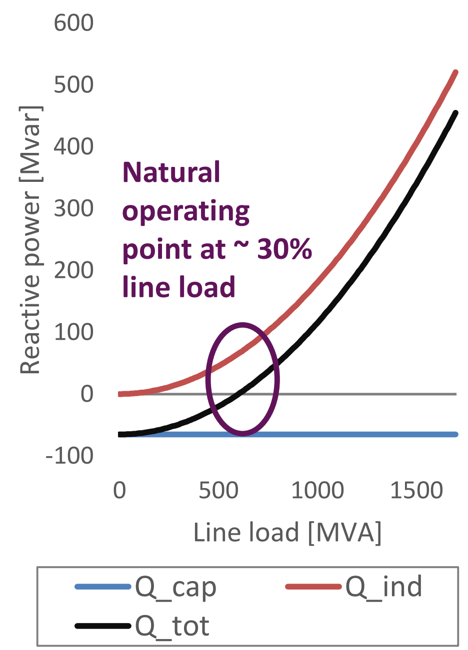
Step 2
Current-induced redispatch

- Estimation of current-induced redispatch based on a **transmission & 110 kV distribution grid** model
- Usage of **ELMOD** to calculate load flows, overloads and **least-cost redispatch**
- Penalty cost for international redispatch

Step 3
Voltage-induced redispatch

- Estimation of **reactive power dispatch** and voltage-induced redispatch
- Usage of **ELMOD LinAC**, a linearized AC model to account for voltage stability and reactive power flows
- **Iterative approach** to account for **quadratic reactive power behavior** of electricity lines

Reactive power behavior of 380 KV line



Iterative calculation of quadratic inductive reactive power behavior

Reactive power provision from the distribution grid and its effects on redispatch cost

Conventional

Redispatch cost: Conventional reactive power supply

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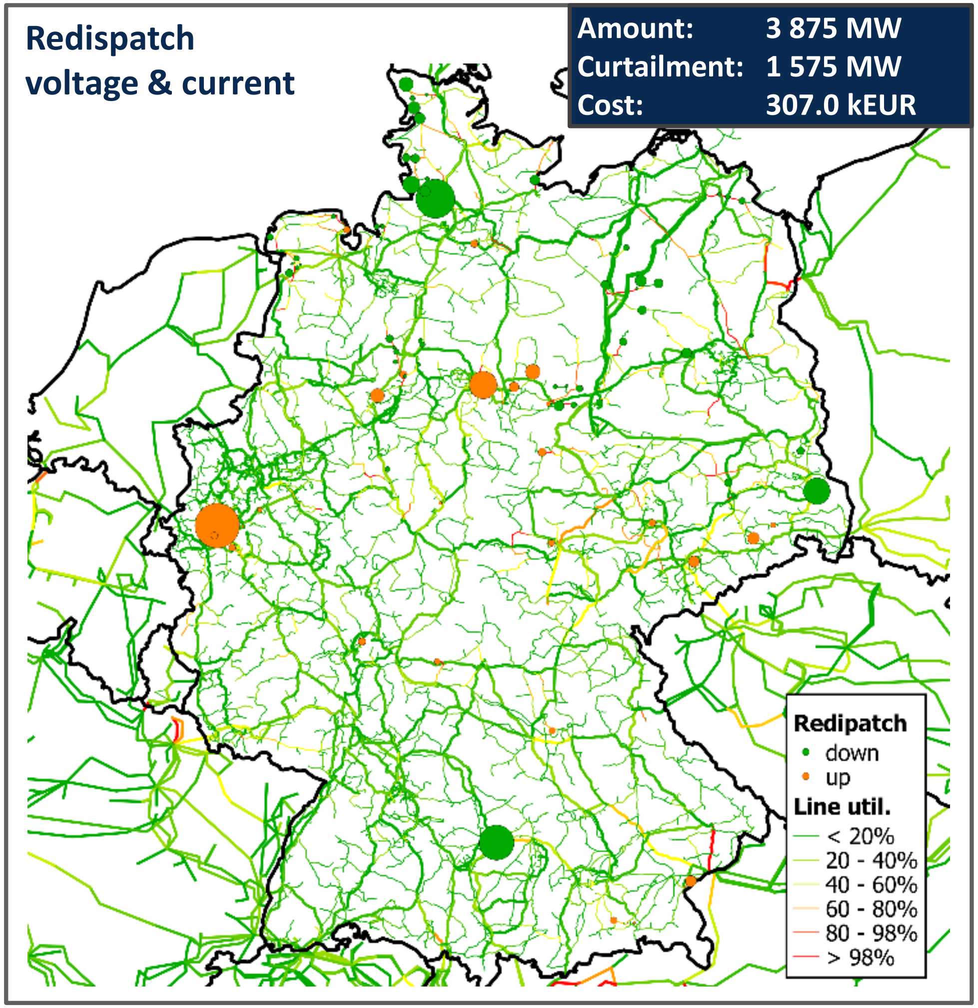
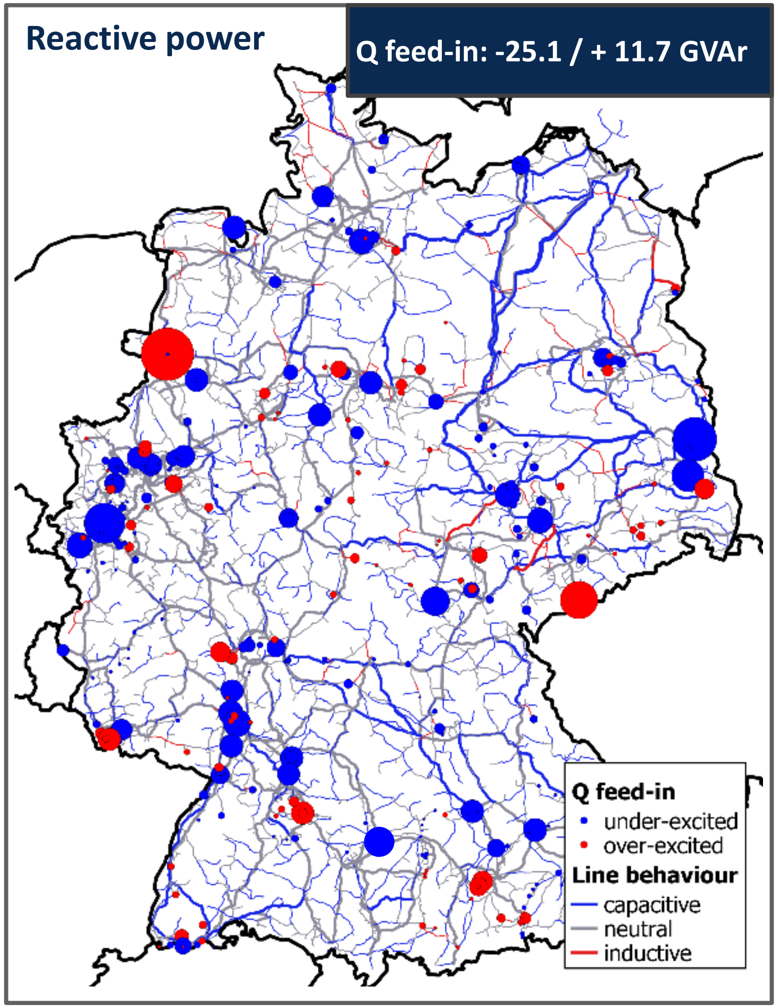
Redispatch and reactive power for very high wind feed-in and low residual load





Redispatch cost:
Q feed-up from distribution grid

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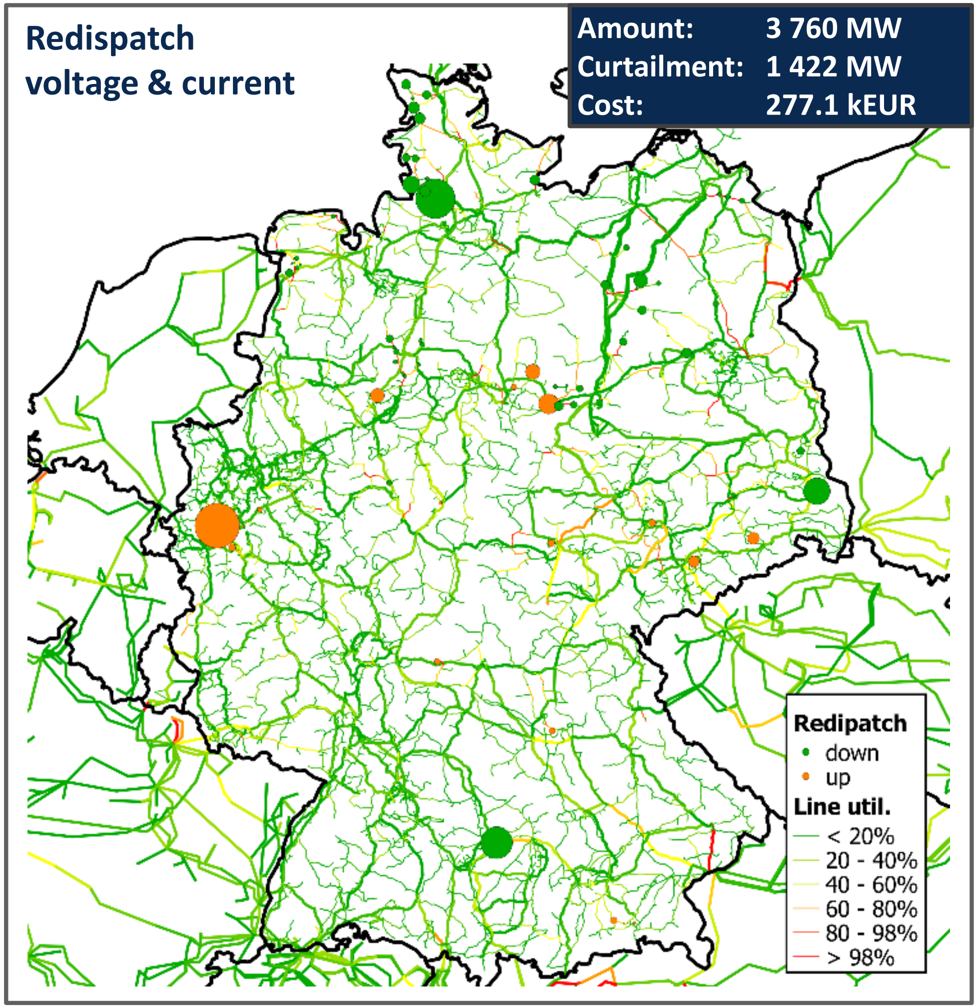
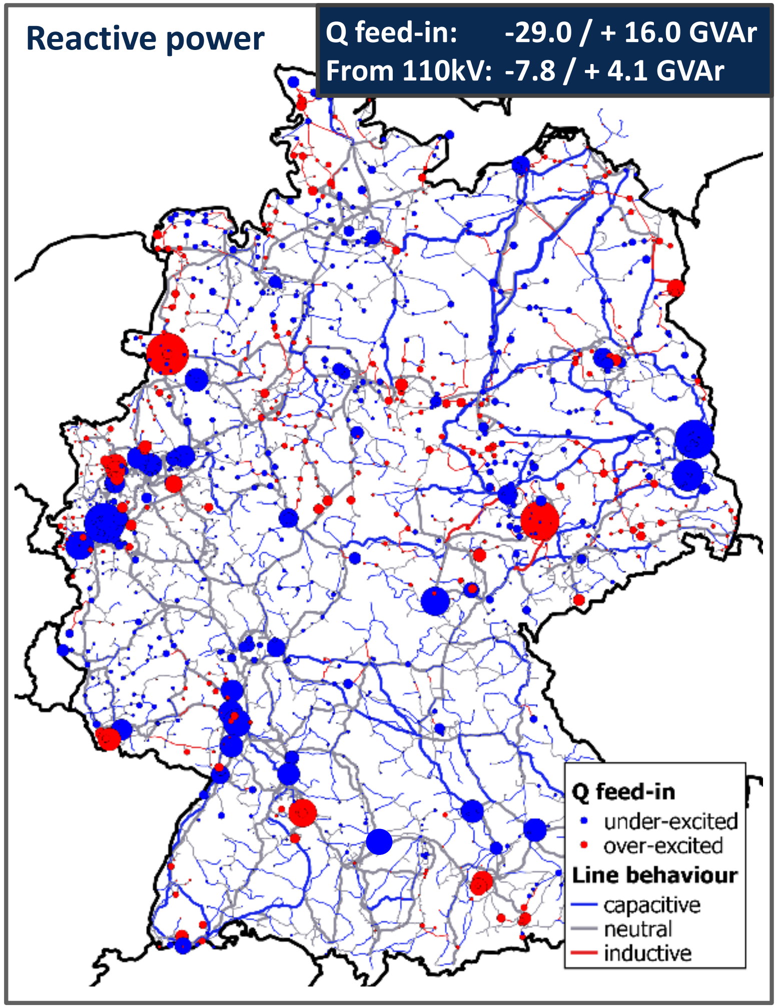
Redispatch and reactive power for very high wind feed-in and low residual load





17.8 mio. EUR of savings due to controlled feed-up of reactive power

Model results: Feed-in and opportunity cost of reactive power, conventional provision

Redispatch & curtailment cost per scenario

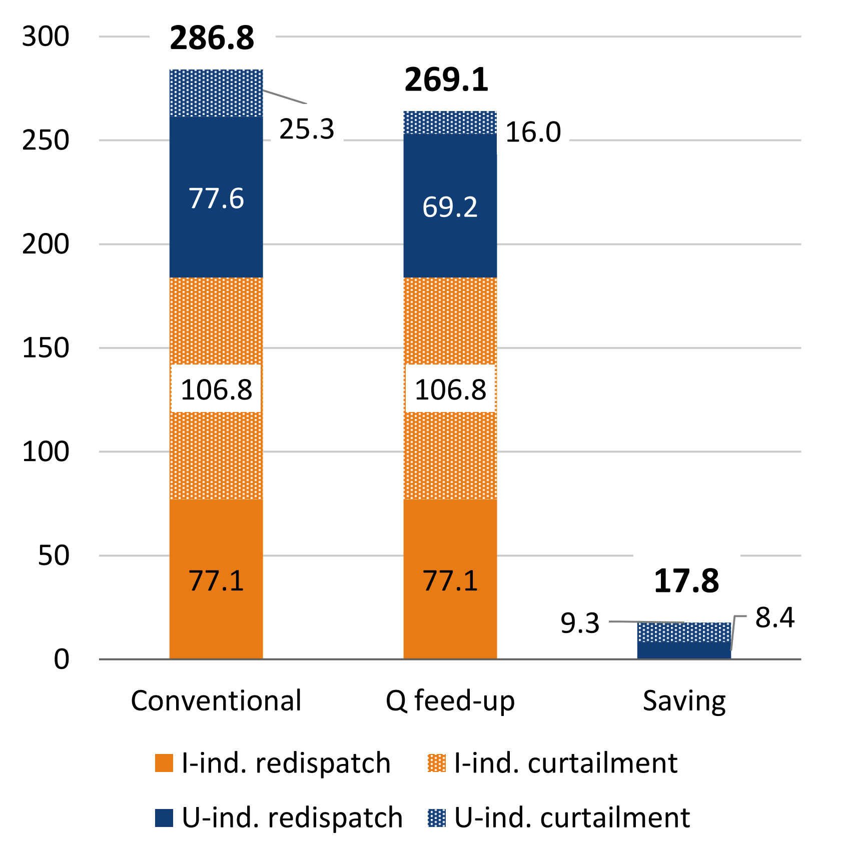
Coventional – Residual load[1)] (kEUR)

Wind	L	M	H	V	Ø
L	1.0	22.3	18.6	165.0	**21.9**
M	0.9	0.6	21.5	144.3	**14.9**
H	0.0	0.1	9.1	54.9	**7.7**
V	307.0	468.1	372.7	598.7	**428.3**
Ø	**4.2**	**21.4**	**35.6**	**135.8**	**32.7**

Q feed-up – Residual load[1)] (kEUR)

Wind	L	M	H	V	Ø
L	1.0	21.5	18.5	164.5	**21.5**
M	0.8	0.6	20.4	142.0	**14.3**
H	0.0	0.1	8.4	51.5	**7.2**
V	277.1	431.9	347.2	568.9	**398.3**
Ø	**3.8**	**19.8**	**33.3**	**130.6**	**30.7**

Yearly cost [mio. EUR]



1) Excluding wind: Demand minus PV

Conclusions and outlook

Conclusions

- **Decentralization** of electricity generation makes the provision of **ancillary services from distribution grids** more important
- **Redispatch cost can be decreased** through the reactive power provision from decentralized RES
- Especially in situations with **very high wind feed-in**, considerable **cost savings** in redispatch and curtailment cost can be achieved
- **ELMOD LinAC** allows **model-based assessment** of both current- and voltage-induced redispatch cost

Outlook

- Scenario-based estimation of redispatch cost for future years (+10 / +20)
- Consideration of different scenarios for
  - Grid extensions
  - Installation of RES
  - Installation / shut-down of conventional power plants