TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Business and Economics, Chair of Energy Economics, Prof. Dr. Möst

Spannungshaltung und Blindleistungsmanagement bei zunehmend dezentraler Stromerzeugung

EE²
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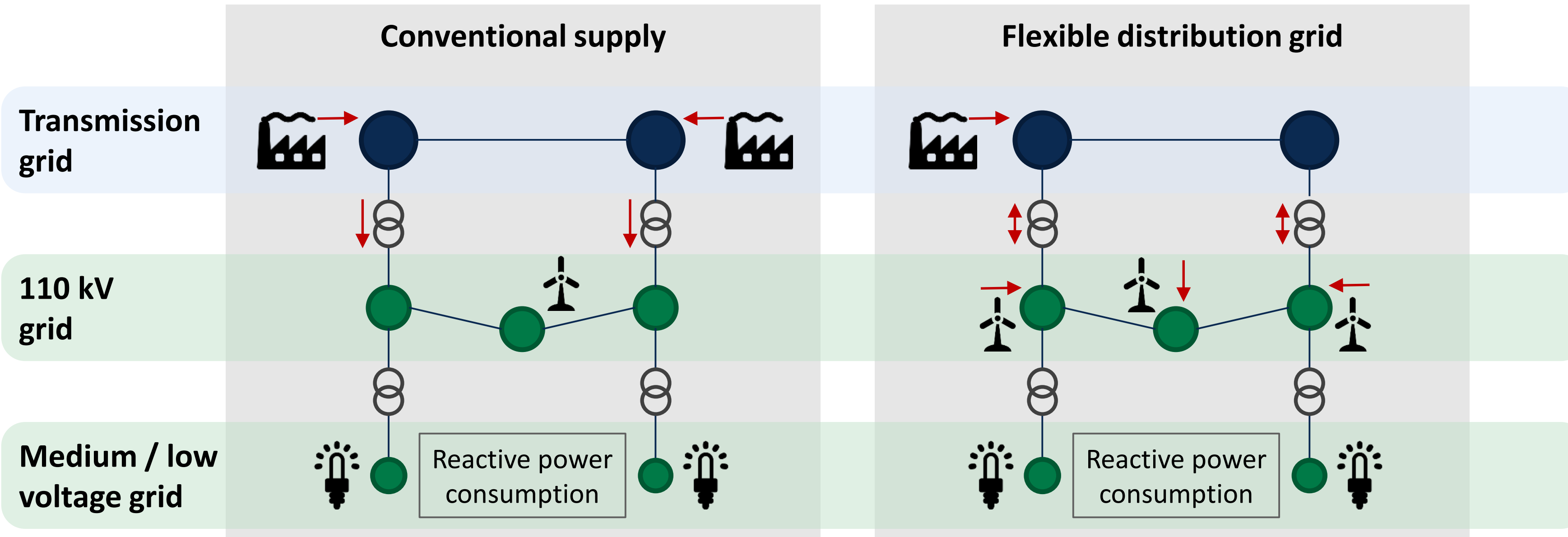
Fabian Hinz

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

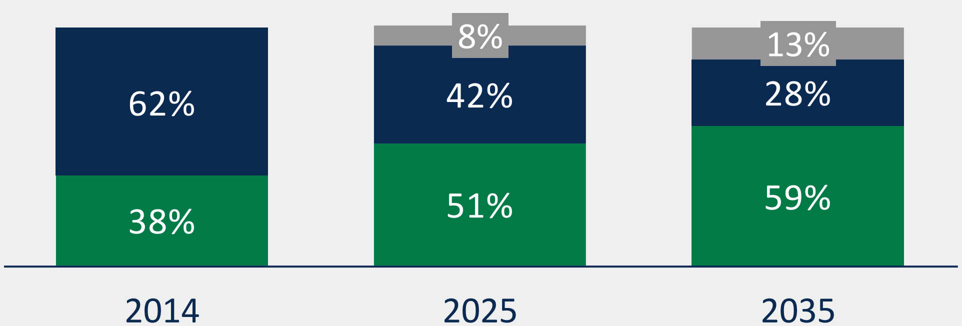
Strommarkttreffen: Verteilnetze
Berlin, 22. September 2017

Reactive power has to be more flexible in the future

Reactive power supply: conventional and flexible scenario



Electricity feed-in Germany



Reactive power supply

- Conventional supply through large power plants and compensators
- Availability in the transmission grid decreases
- Supply can be replaced by RES in the distribution grid

Flexible reactive power | Offshore | TSO | DSO

Source: Kraftwerksliste BNetA 2015, Netzentwicklungsplan 2025
Icons made by Freepik from www.flaticon.com

Currently, reactive power remuneration does not incentivize flexibly supply

Usage and remuneration of reactive power in Germany

Remuneration

Reactive power tariffs exist in the form of penalties for excessive reactive power consumption and bilateral contracts.

Transmission grid

Conventional power plants
- Bilateral contracts for reactive power

Interface TSO / DSO
- Reactive power tariffs
- No incentive for flexibility

110 kV grid

Renewable Energy Sources
- Obligatory provision
- No incentive for flexibility

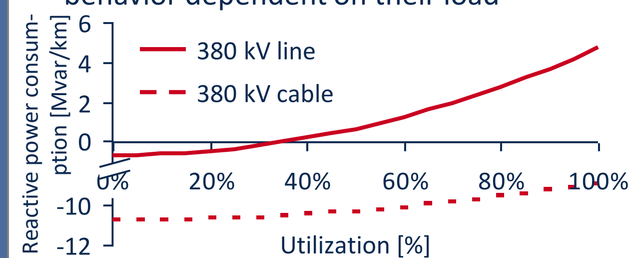
Medium / low voltage grid

Final customers
- Reactive power tariffs
- No incentive for flexibility

Usage

Voltage control
- Reactive power flows along a voltage differential
- Voltage increase through feed-in of inductive reactive power
- Voltage decrease through feed-in of capacitive reactive power

Compensation of transmission equipment
- Transmission lines show a reactive power behavior dependent on their load



Reactive power consumption of customers

Which are the benefits from a flexible supply and how can it be remunerated?

Model developed in order to assess the benefits of flexible reactive power

Simplified model formulation of ELMOD AC and ELMOD LinAC

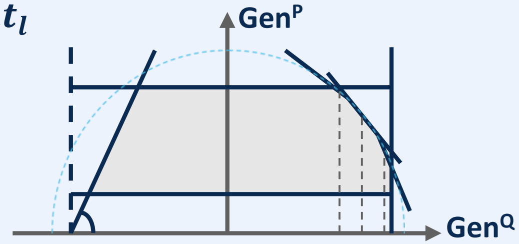
Target function: $\text{Min} \sum_{n \in N} cost_n^{marg} \cdot Gen_n^P$

Thermal limit: $LineCurrent_l \leq Thermallimit_l$

Voltage range TS: $0{,}97\ p.u. \leq U_n \leq 1{,}03\ p.u.$

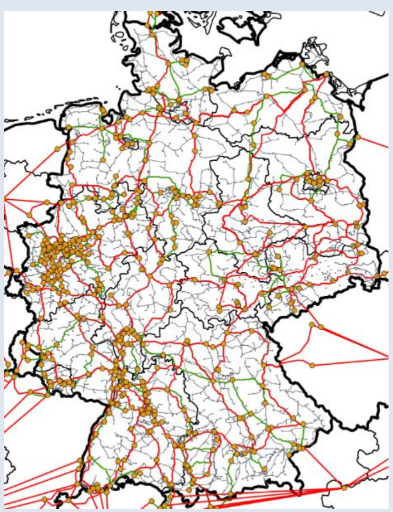
Voltage range DS: $0{,}94\ p.u. \leq U_n \leq 1{,}06\ p.u.$

Generator capability curve: $\begin{pmatrix} Gen_n^P, \\ Gen_n^Q \end{pmatrix} \in$



Grid balance

ELMOD LinAC



Real power:

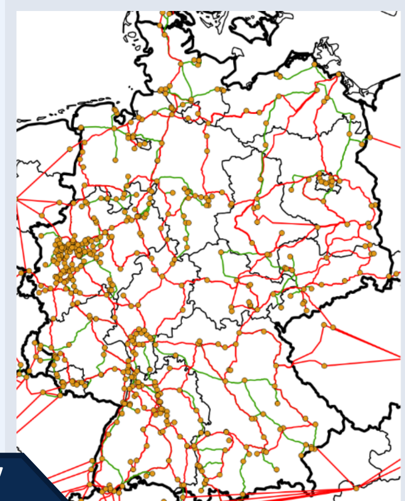
$$Gen_n^P - Dem_n^P - Loss_n^P = \sum_{m \in N} (g_{n,m}(U_n - U_m)$$

Iterative calculation

Reactive power:

$$Gen_n^Q - Dem_n^Q - Loss_n^Q = \sum_{m \in N} (-b_{n,m}(U_n - U_m)$$

ELMOD AC



Real power:

$$Gen_n^P - Dem_n^P = \sum_{m \in N} U_n U_m \cdot (g_{n,m} cos(\theta_n - \theta_m))$$

Non-linearities

Reactive power:

$$Gen_n^Q - Dem_n^Q = \sum_{m \in N} U_n U_m \cdot (g_{n,m} sin(\theta_n - \theta_m))$$

Nodal 110 kV potentials

1) U_n / U_m... Voltage magnitude at node n / m Θ_n / Θ_m... Voltage angle at node n / m $g_{n,m}$ / $b_{n,m}$... Conductance / susceptance between node n and m

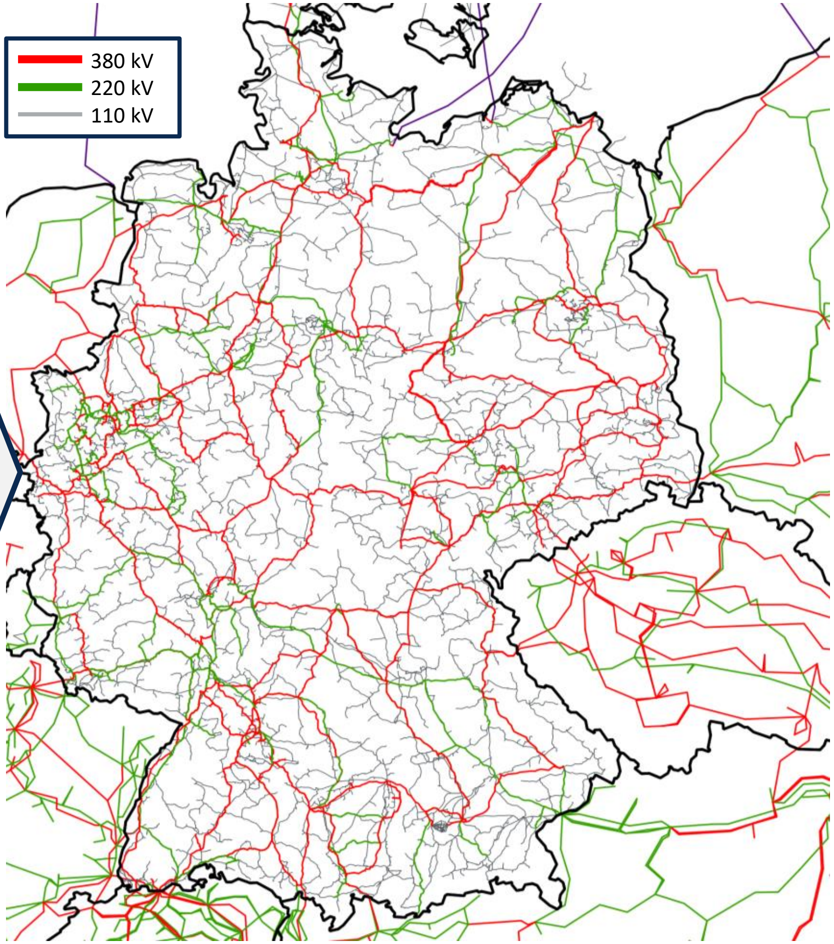
Model applied to 110 kV grid set based on OSM data and other public sources

Data set for grid model

OSM data

- **Substations**
  380 / 220 / 110 kV
- **Electricity lines**
  380 / 220 / 110 kV

- **Nodes** with generation and demand
- **Auxiliary nodes**
- **Lines** start / end, technical parameters
  updated with TSO static grid models
- **Transformers**
  380 / 110 kV
  220 / 110 kV



Power plants / RES

Attribution to nodes

- **Plants:** based on addresses and coordinates
- **RES:** based on OSM data / RES database

Load

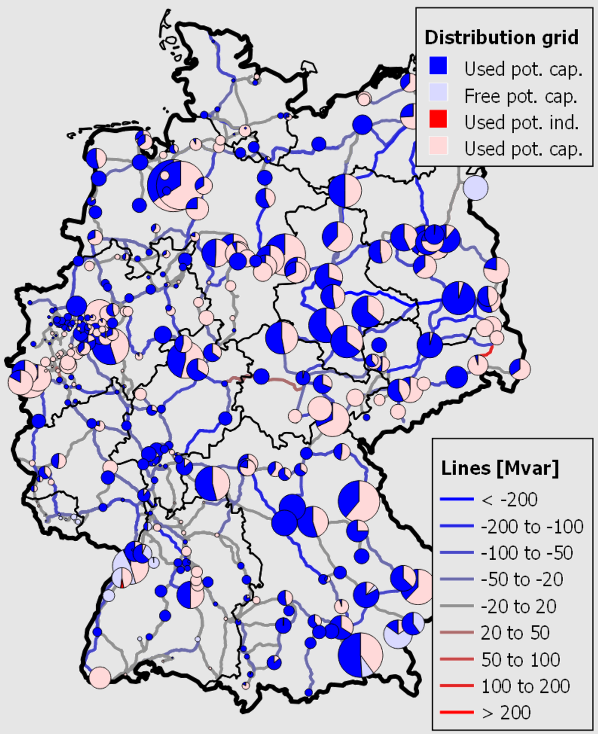
- Attribution based on GDP and population of surrounding area

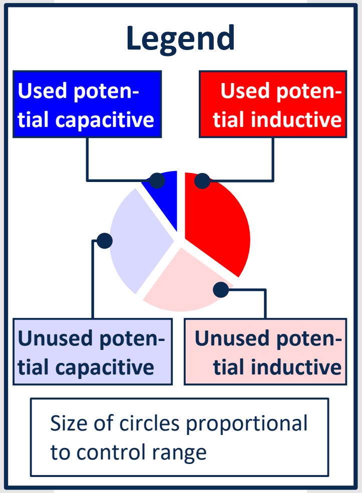
Nodes:	~5700
Lines:	~6500
Substations:	~370

Availability and usage of reactive power depends on grid situation

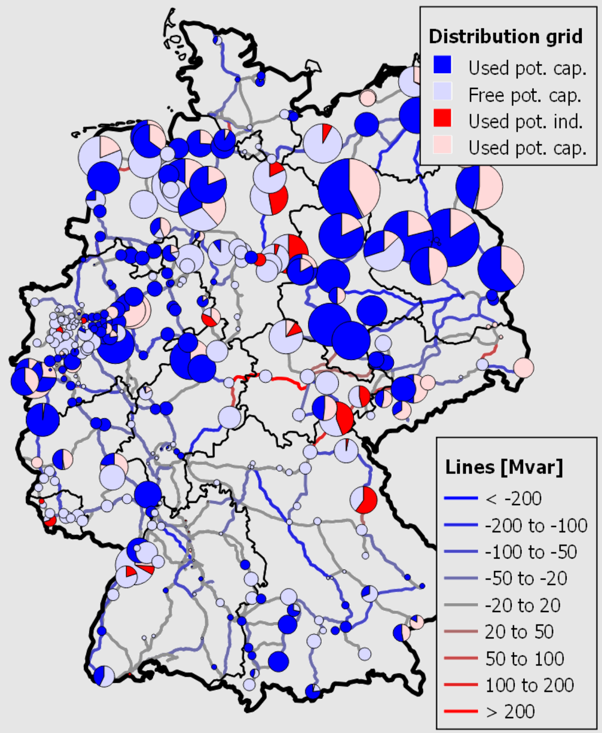
Potentials estimated with ELMOD LinAC and usage calculated with ELMOD AC

Low wind, low load





High wind, high load



Results

- Small potentials from 110 kV grid (conv. plants)
- Potential inductive due to inductive MV behavior
- Usage of capacitive potential due to idle grid

- Large potentials from 110 kV grid
- Potential mostly capacitive due to inductive load
- Usage of inductive potential due to loaded grid

Reactive power supply from decentralized sources can save operational cost

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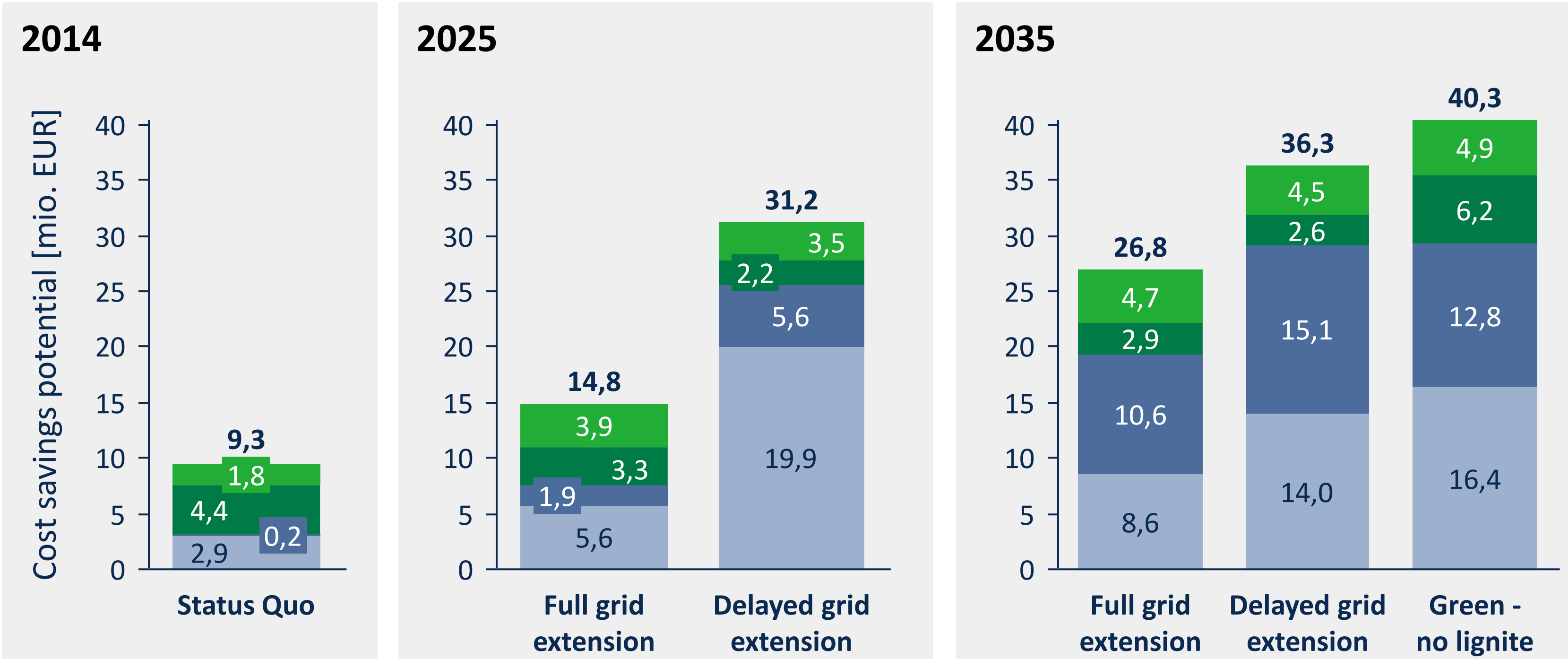
Annual savings potential in operational cost through decentralized reactive power sources, in mio. EUR



Results

- Certain **cost saving** potential already in the **status quo**
- Savings potential mainly from **loss reductions**

- **Increasing savings potential** in delayed grid scenario
- Large savings in **redispatch**
- ➢ **Significance of reactive power concept increases** with delays in grid extension

- Higher saving potential when grid extension is delayed, especially in combination with lignite phase-out
- Savings in **redispatch and curtailment**

Losses DS | Losses TS | Curtailment | Redispatch

High savings potential in situations with a low residual load

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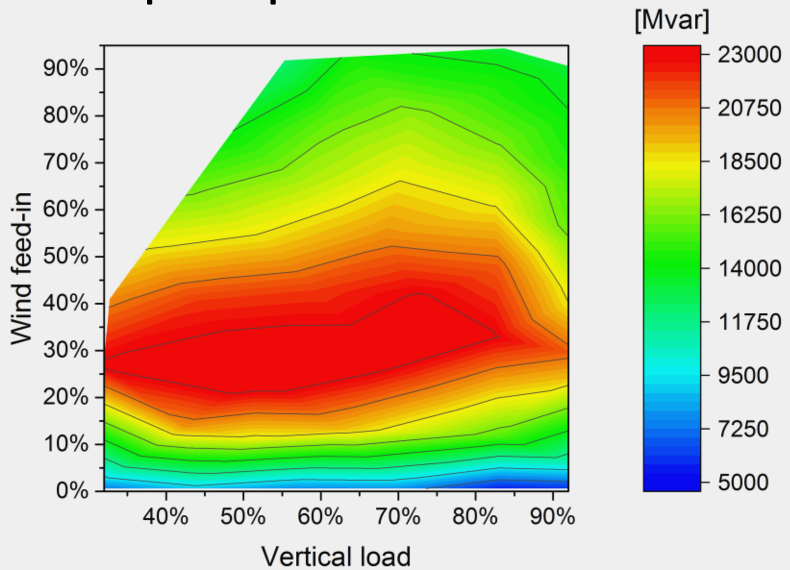
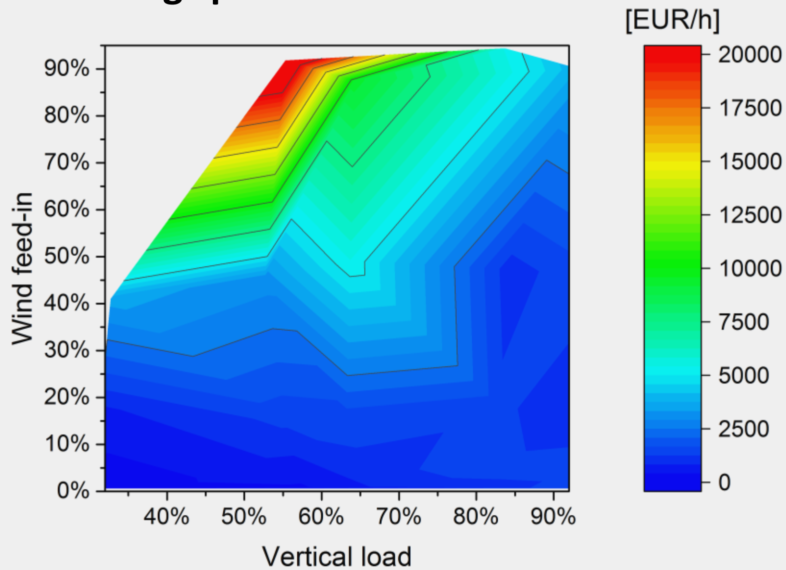
Comparison of reactive power and savings potential per grid situation

Reactive power potential



- Highest potential between 20% and 40% wind feed-in
- Potential around 0% wind feed-in results from conventional power plants in the 110 kV grid
- Above 50% wind feed-in reduced potential due to congestions and reaching of voltage limits

Cost savings potential

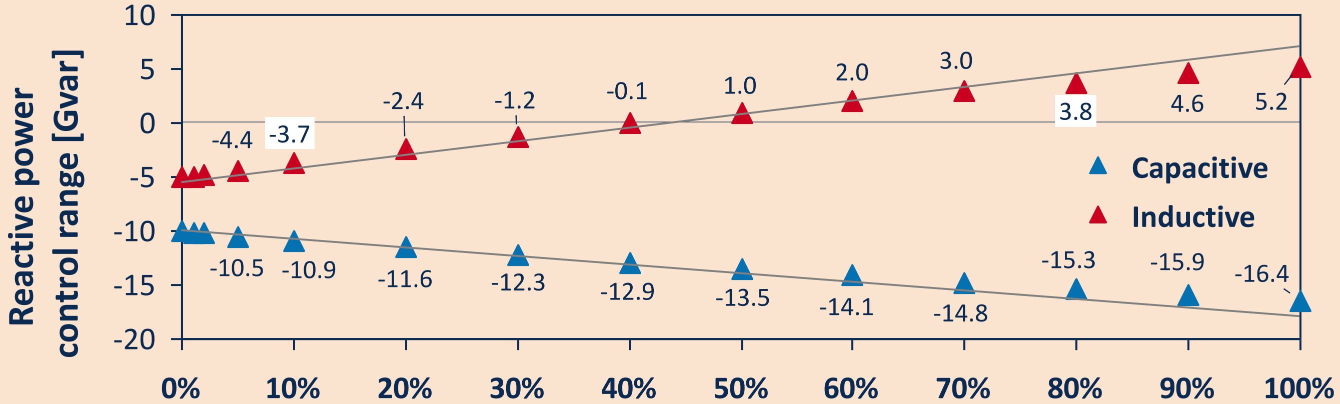


- Moderate savings potential in areas of low and medium wind feed-in as well as medium and high load
- Largest savings potential at high wind feed-in and low load
  - Due to low residual load, only a few conventional power plants are dispatched
  - Wind turbines provide a sufficient reactive power potential

Which situations lead to a high need for reactive power from the distribution grid?

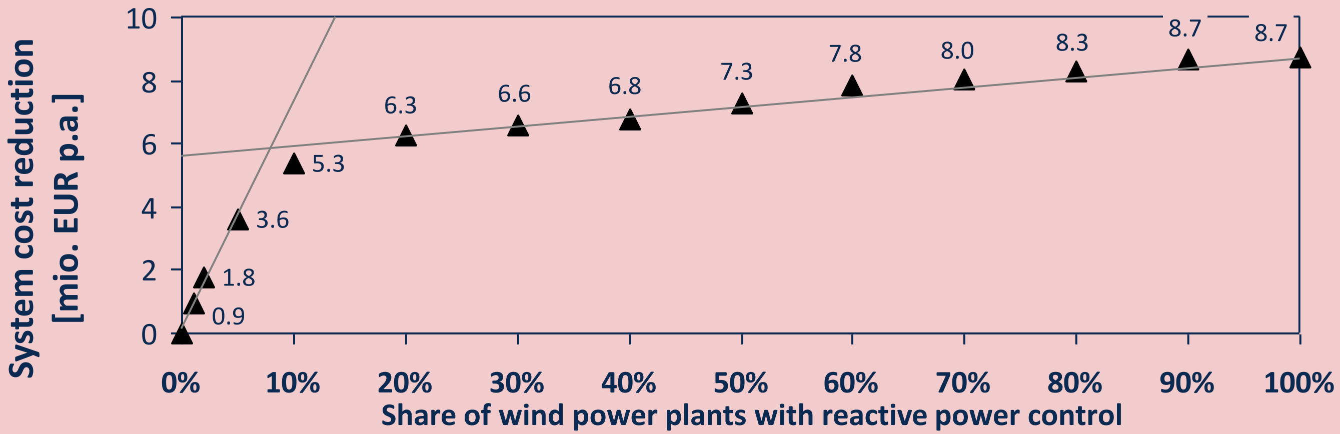
Only a small share of potential reactive power sources has to be made available

Reactive power control ranges and cost savings under different shares of wind power inclusion



Increasing share of wind power plants with reactive power control

→ Aggregated control range in Germany 2025 increases slightly less than proportional



→ System cost reductions show limited growth

→ 72% of cost reductions achieved with a 20% share of wind power plants

How many reactive power sources should be made available?

Alternative remuneration mechanisms could leverage reactive power flexibilities

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Alternative remuneration concepts for reactive power

Market-based

Prices are an outcome of an open competition between suppliers and demander(s), regulation only determines the framework

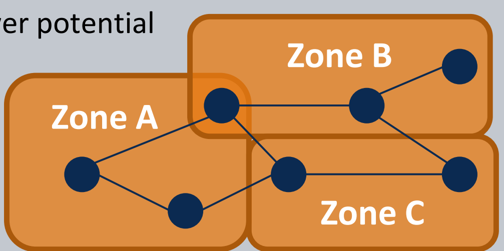
Bilateral agreement

Long-term tenders[2)]

Nodal / zonal spot markets

- Constitution of short-term markets for reactive power similar to electricity markets
- Zonal or nodal market design due to the the local nature of reactive power
- TSO could act as auctioneer in a monopsonic market environment to cover system requirements
- Volatile sources can bid based on their actual reactive power potential

Zonal layout:



Regulatory

Reactive power obligations and / or tariff calculations fixed on a regulatory basis

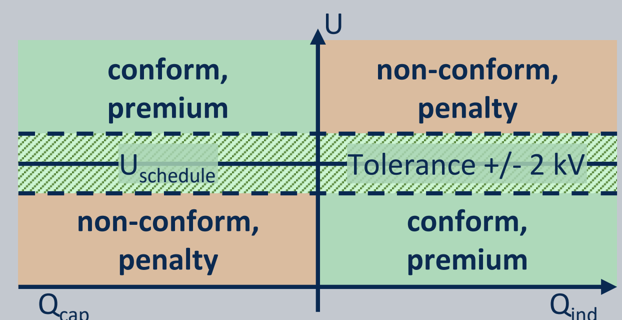
Obligatory provision

Regulated tariffs[1)]

Voltage-based premium

Applied in Switzerland

- DSOs and large customers can choose between **active and passive participation**
- Active participants receive a **premium for conform** and pay a **penalty for non-conform** behavior
- Scheme for **active participants**:



1) For reactive power reserve or dispatch 2) Only for reserve premium or for reserve premium and dispatch prices

Conclusions

Benefits

- Additional reactive power mostly required in **low residual load** situations
- Flexible reactive power from 110 kV RES can reduce operational cost up to **40 mio. EUR,** especially if **grid extension is delayed**
- **Large part of savings** can be generated with a **small amount of sources**

Remuneration

- Current mechanisms **not sufficient to incentivize** flexibility
- **Regulatory or market-based** concepts exist

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Thank you for your attention!

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