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Hosted by: Fraunhofer CINES + GUROBI OPTIMIZATION

Energy Innovation Summit

Optimization Strategies for the Energy Transition

March 13 - 14, 2024 Frankfurt / Frankfurt, HE

Denis Mende, 13.03.2024

Challenges in Power System Operation

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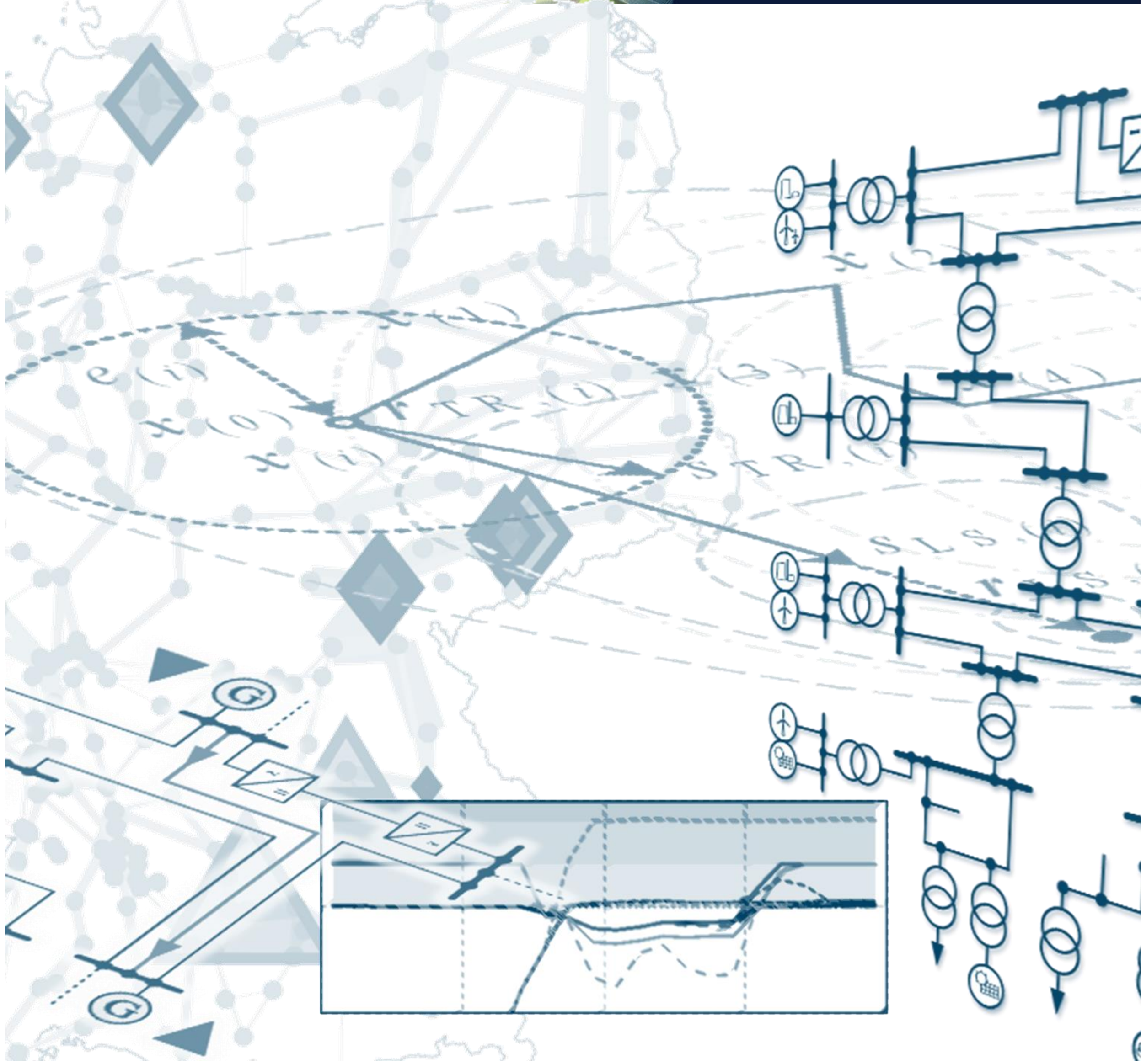

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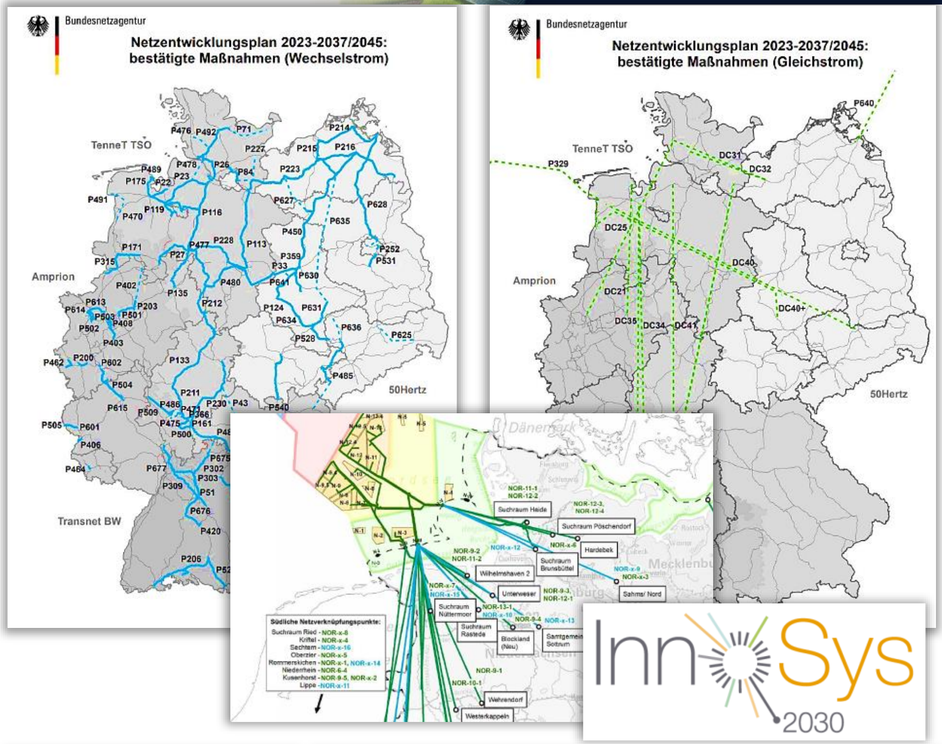
Motivation & Needs

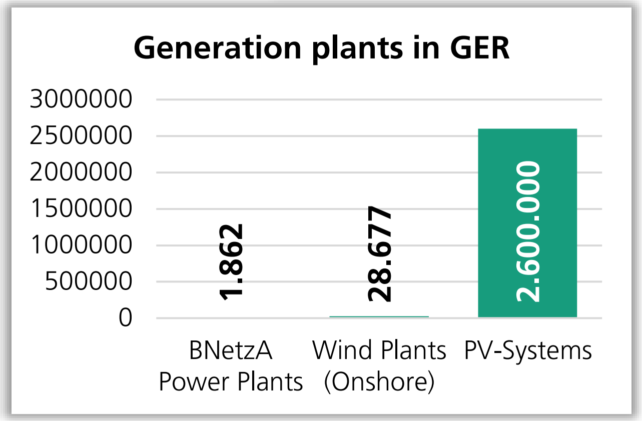
Challenges in Power System Planning and Operation

Current developments in the German power system

- Confirmation of the current grid development plan (BNetzA1)
  - New/upgraded AC-Systems → complexity and expansion processes
  - DC-Systems → combined AC/DC-power system
  - Offshore generation → DC-Systems & power transfer needs
- Operational challenges (loadings, expansion process, …) and new approaches (power flow control, curative operation, …) (InnoSys)
- Ongoing decentralization of power generation
  - Dramatically increased number of power plants (BNetzA2, Statista, Destatis)
- Regulatory changes and demands
  - EnWG §14a: Flexibility regulations for demand side in LV
  - EnWG §14d: Need for grid expansion plans also by DSOs (BAGE)

▶ **Ongoing increase of demands and complexity**





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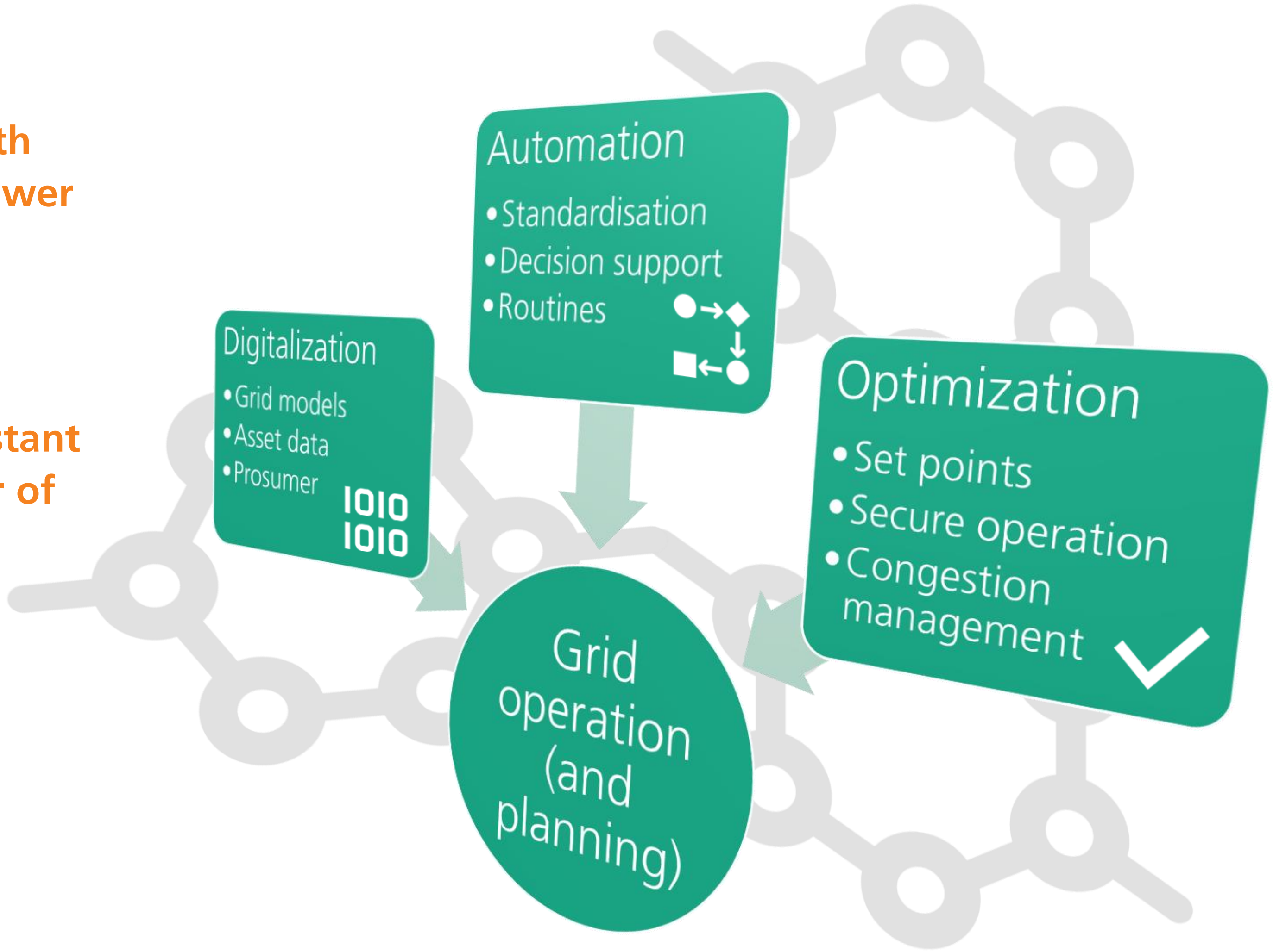
Motivation & Needs

Challenge characteristics & approaches

„… from small, predictible power system with overseeable number of flexibilities by large power plants

to

decentralized, highly loaded systems with constant action and control needs with a great number of possible flexibility providers …“



▶ **How to handle this…**

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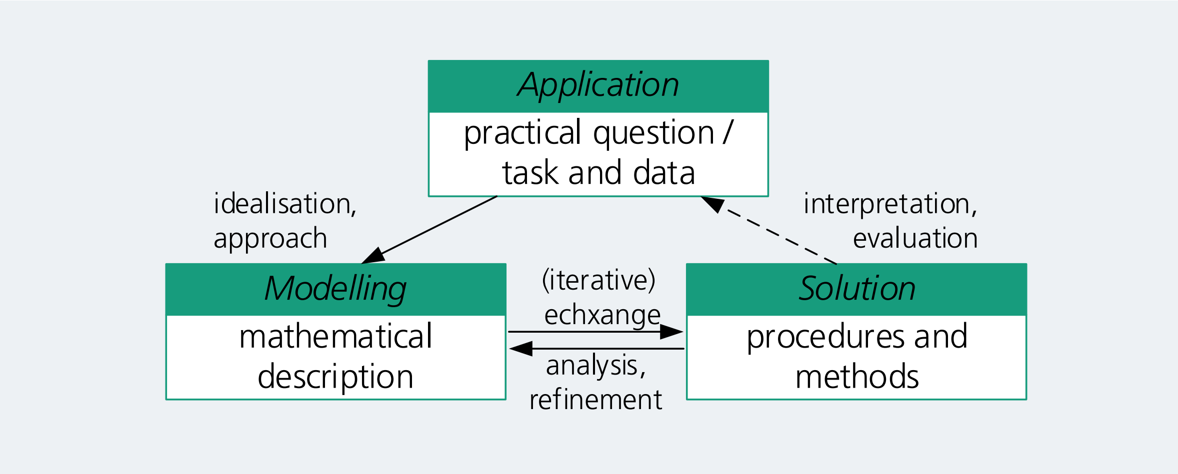
Modelling aspects

Optimization problem and solving approaches

Approach to problem simulation using mathematical optimization methods

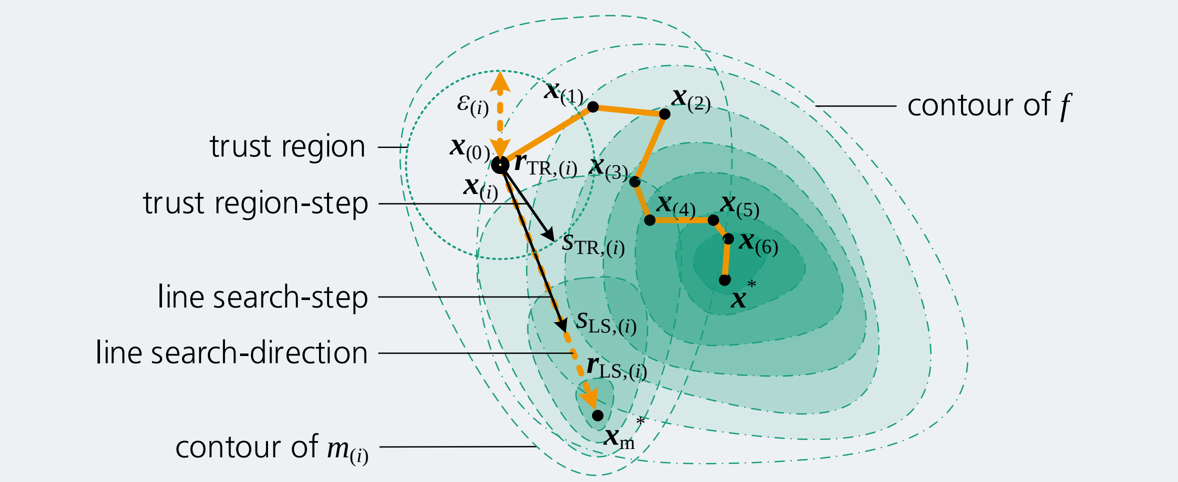
- Application problem → Modelling → Solution
- (electro-)technical dependencies can be described mathematically
- Exact reproducibility of results



Inclusion of derivation information in the solving process important issue (and possible strength)

Exemplary iterative methods for problem solving

- Line search (focus on search direction)
- Trust region (focus confidence interval)



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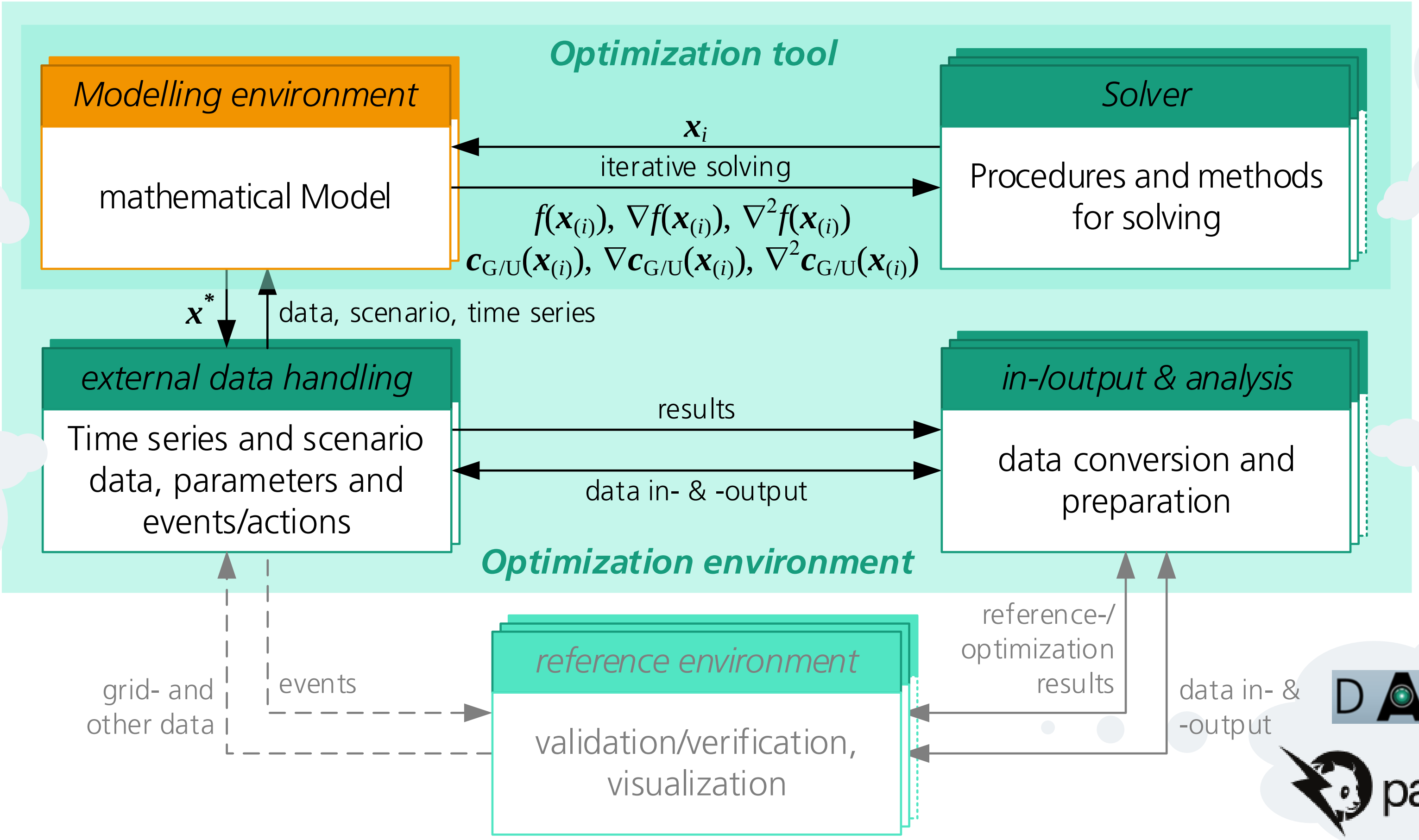
Modelling aspects

Implementation possibilities



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Modelling

Power flow and flexibility problem integration

Bus-based power flow formulation

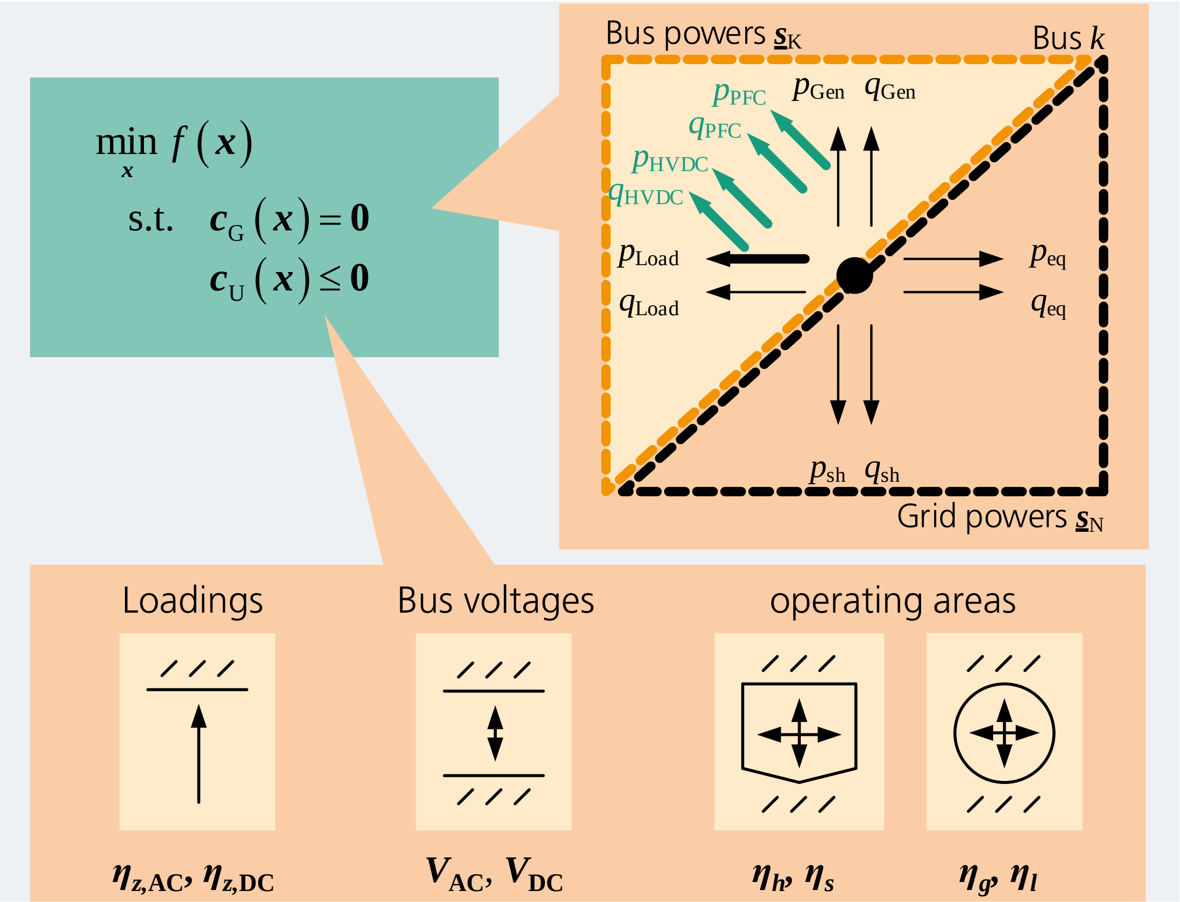
$$0 = -\sum P_{\mathrm{Gen},k} + \sum P_{\mathrm{Load},k} + \sum P_{\mathrm{PFC},k} + \sum P_{\mathrm{HVDC},k} + \sum_i V_k V_i \left(g_{ki} \cos\left(\varphi_k - \varphi_i\right) + b_{ki} \sin\left(\varphi_k - \varphi_i\right)\right) \quad , \forall k$$

$$0 = -\sum Q_{\mathrm{Gen},k} + \sum Q_{\mathrm{Load},k} + \sum Q_{\mathrm{PFC},k} + \sum Q_{\mathrm{HVDC},k} + \sum_i V_k V_i \left(g_{ki} \sin\left(\varphi_k - \varphi_i\right) - b_{ki} \cos\left(\varphi_k - \varphi_i\right)\right) \quad , \forall k$$

Flexibilities modelled as additional bus powers

- P/Q-flexibilities of generation/demand:
  Redispatch, feed-in management (RD2.0, …)
- Operation schemes and power flow control (FACTS etc.)
- HVDC-Systems (setpoints/control modes)

Technical boundaries as further constraints



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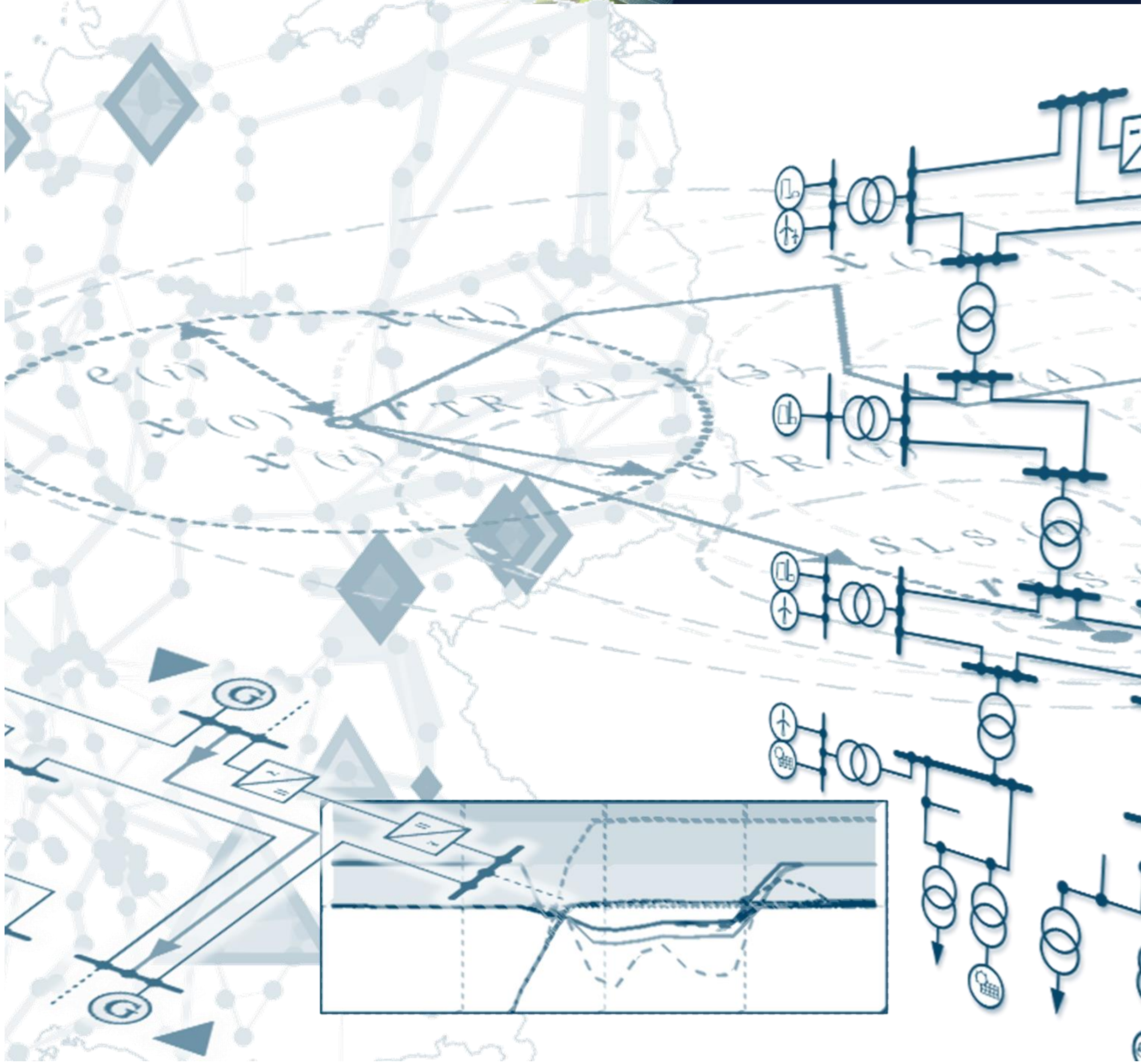

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Application examples

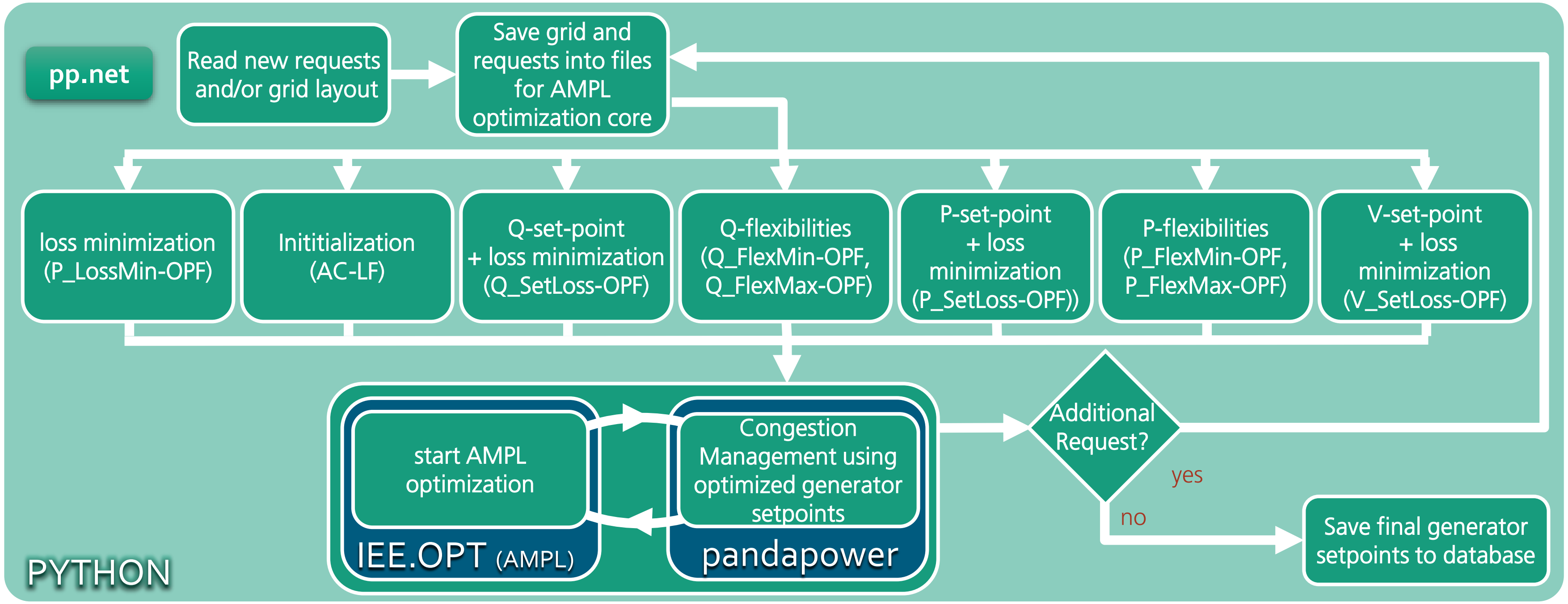
Flexibility assessment at TSO-DSO interface (I/II)

Approach & Implementation

- Real world application based on different (parameterizable) objectives
- Data flow integration (“open loop”)

Application on real grid (Saxony-Anhalt):

- 2 Net Groups (NG)
- 5 Grid Connection Points (GCP)
- 10 TSO-DSO Transformers (380kV/110kV)
- 379 Grid Buses
- 41 Generators (thereof 29 controllable Generators)



Application examples

Flexibility assessment at TSO-DSO interface (II/II)

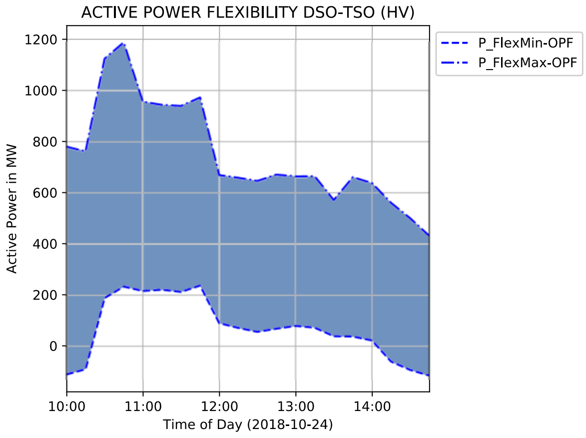
Flexibility & loss evaluation using dec. flexibilities

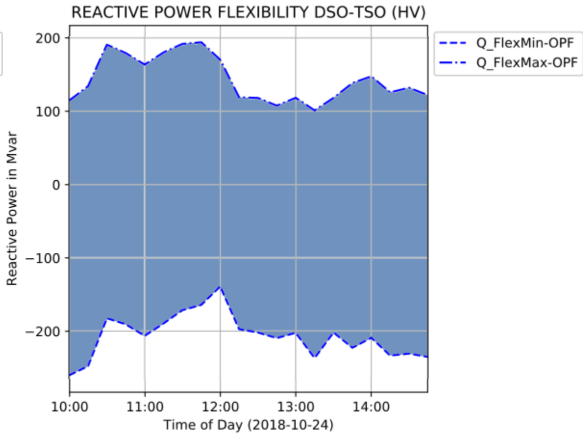
- Active power
- Reactive power
- Losses

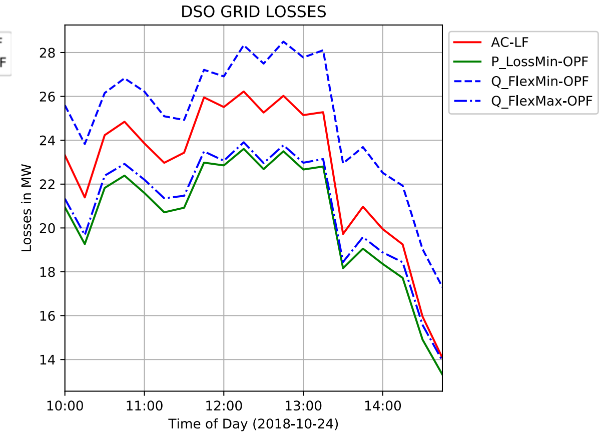
Setpoint realisation using decentralized flexibilities

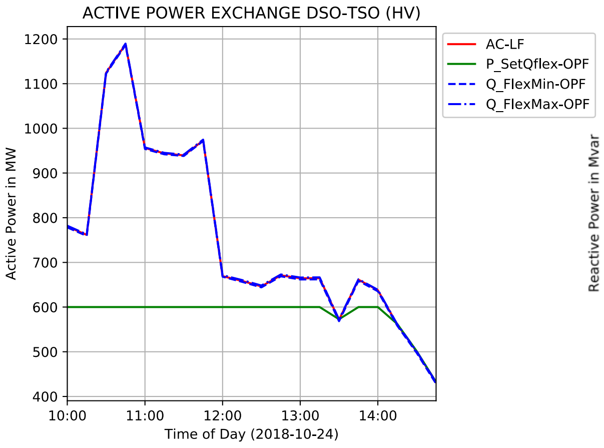
- Active power
- Reactive power
- Voltage

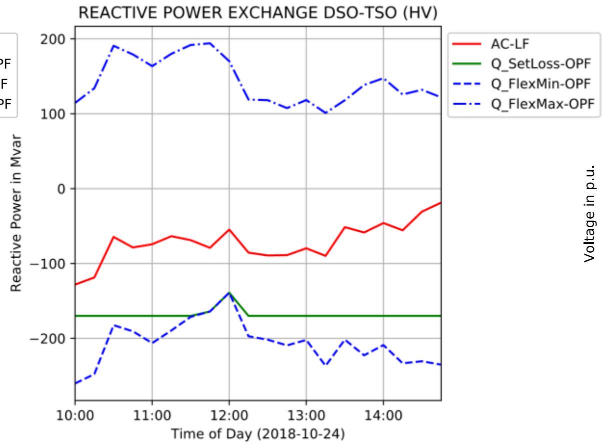
▶ **Reliable and stable optimization integration for several months**

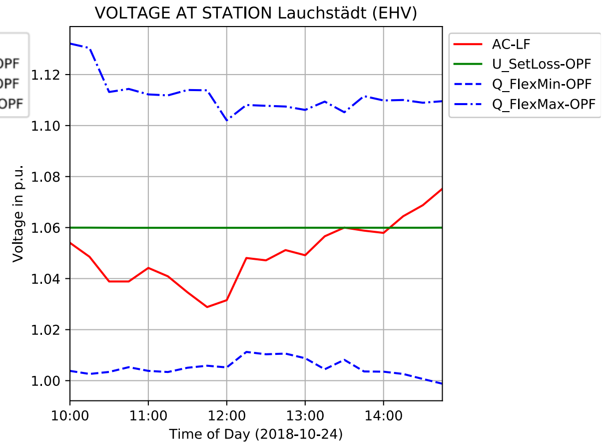












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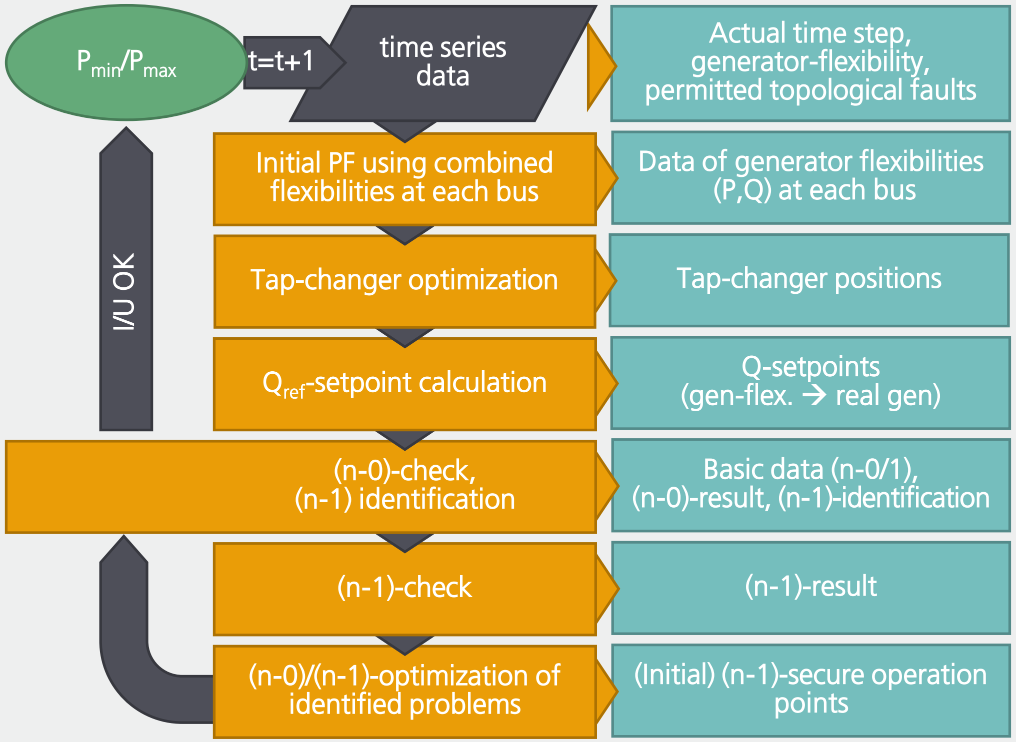
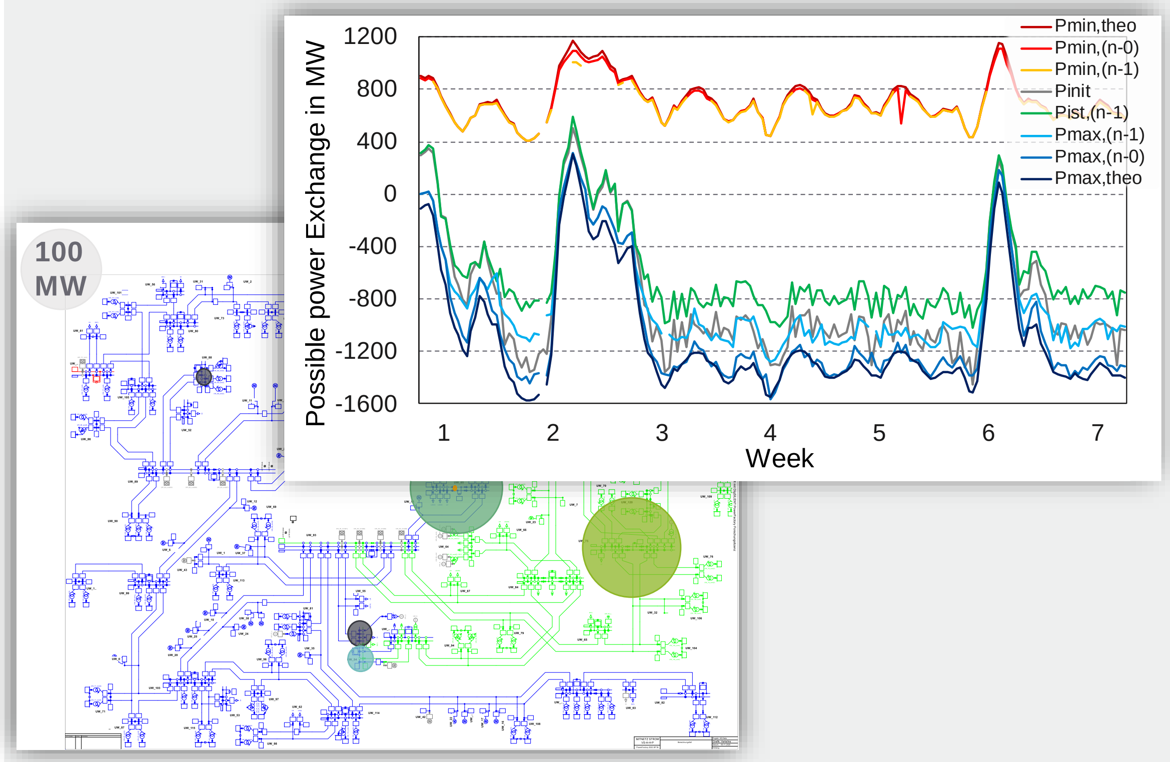
Application examples

Security-dependent flexibility assessment

Overview on approach and implementation steps



HV grid application / exemplary results



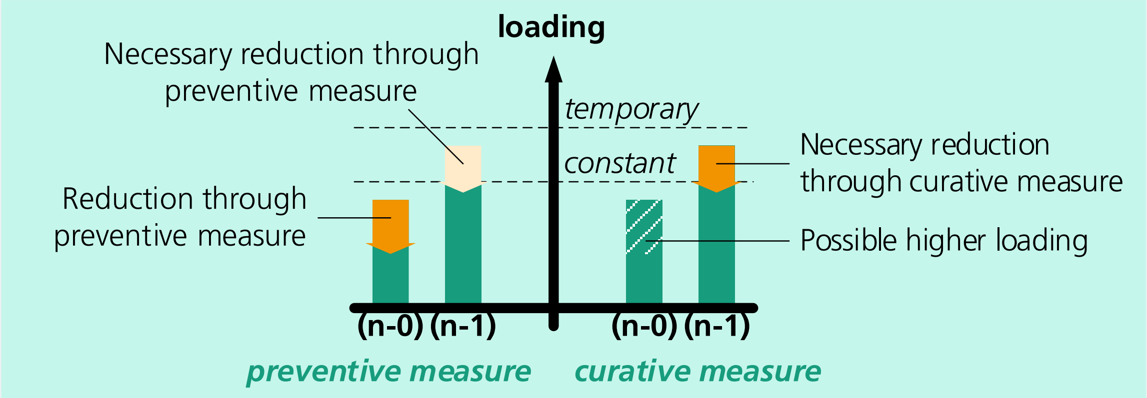
▶ **Support of operational planning processes through flexible application in various current operational issues**

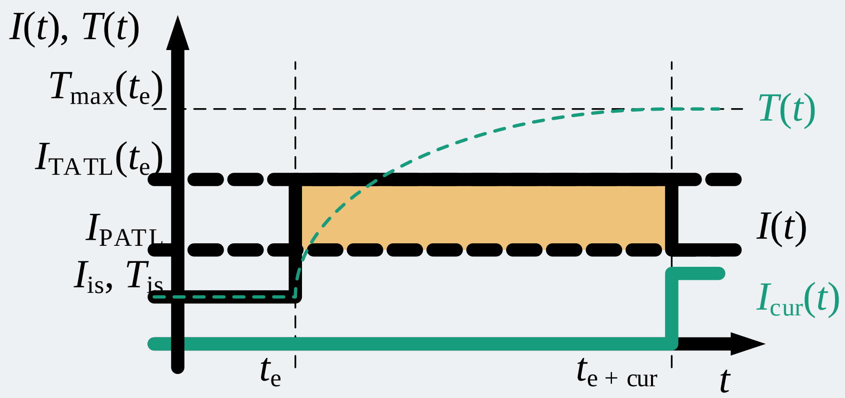
Application examples

Operative & curative congestion management (I/III)

Background

- Increase in usable transmission capacity through innovative grid operation
- Dimensioning of the curative measure





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Application examples

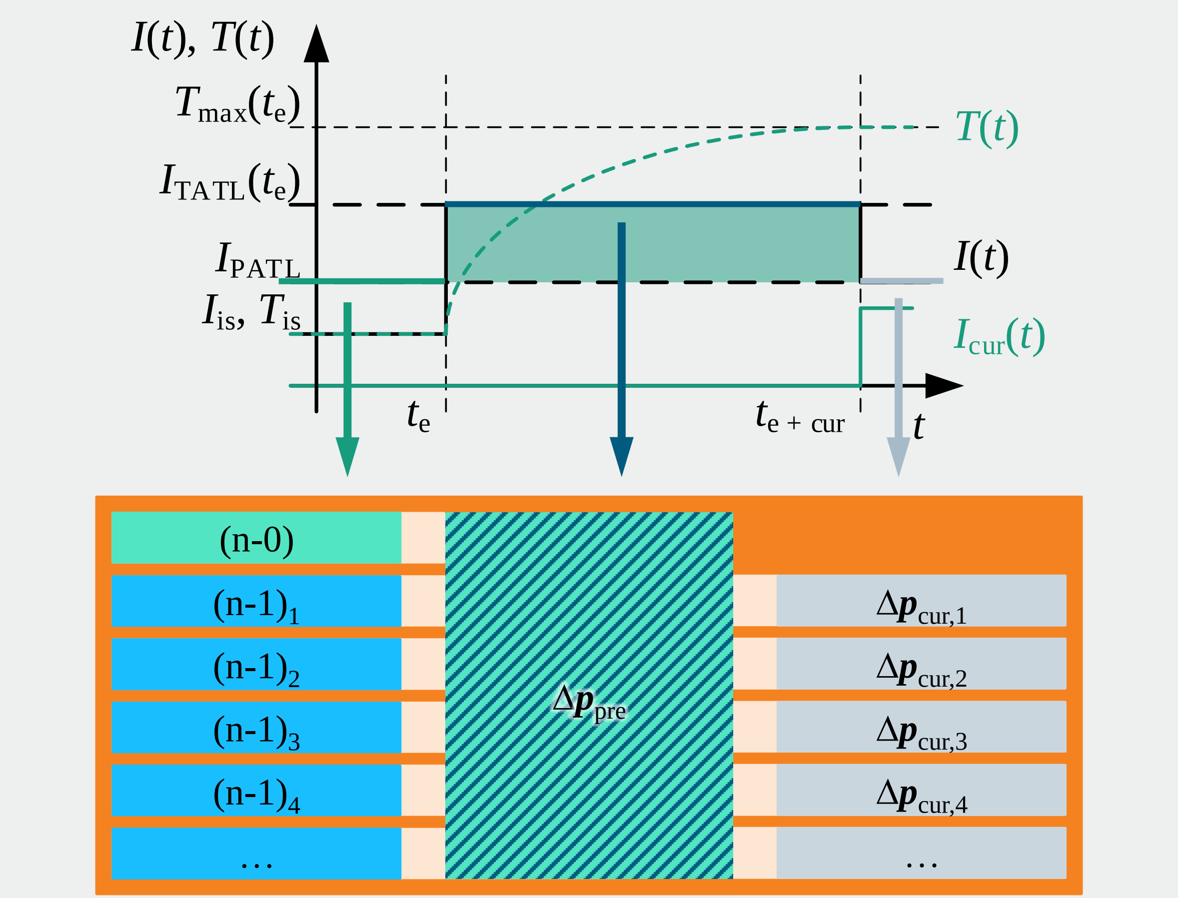
Operative & curative congestion management (II/III)

Background

- Increase in usable transmission capacity through innovative grid operation
- Dimensioning of the curative measure

Modeling approach

- Fault variants and preventive/curative measures: Scenario-dependent limits and flexibilities



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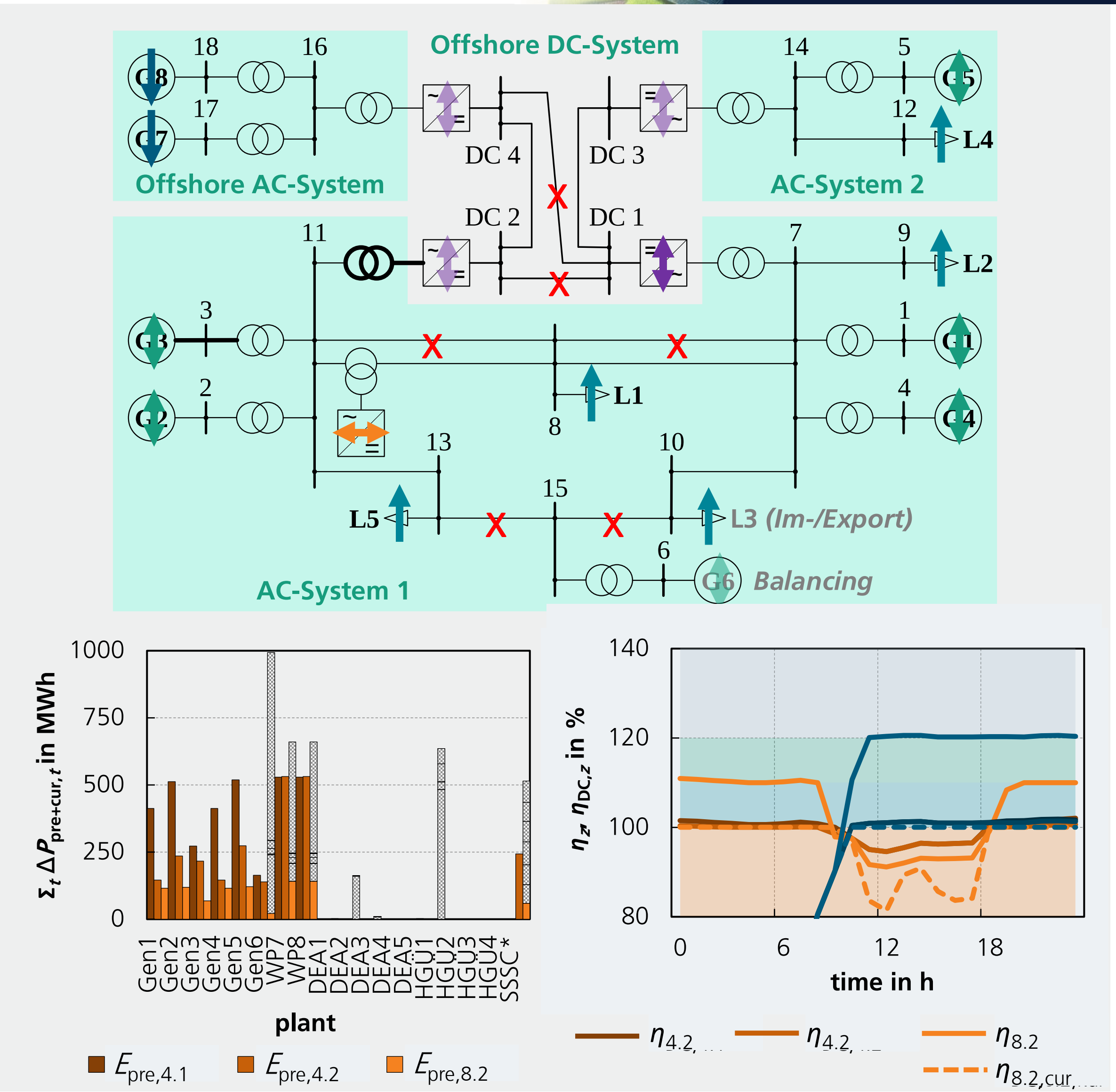
Application examples

Operative & curative congestion management (III/III)



Background

- Increase in usable transmission capacity through innovative grid operation
- Dimensioning of the curative measure

Modeling approach

- Fault variants and preventive/curative measures: Scenario-dependent limits and flexibilities

Application example

- Combined AC/DC system with various flexibilities
- Bottlenecks can be avoided through operational congestion management measures

▶ **Implementation approach allows to handle problem complexity**

See also: Denis Mende: ‚Modellierung von Maßnahmen der Leistungsflusssteuerung in einer nicht-linearen mathematischen Optimierung zur Anwendung im operativen Engpassmanagement elektrischer Energieversorgungssysteme‘. DOI: 10.24406/publica-fhg-416660.

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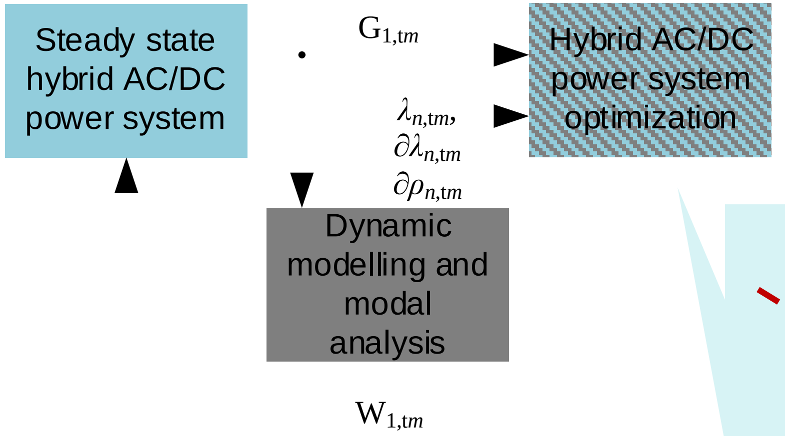
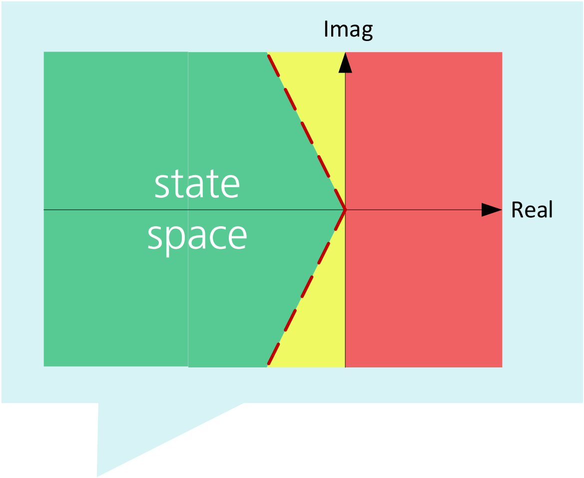
Application examples

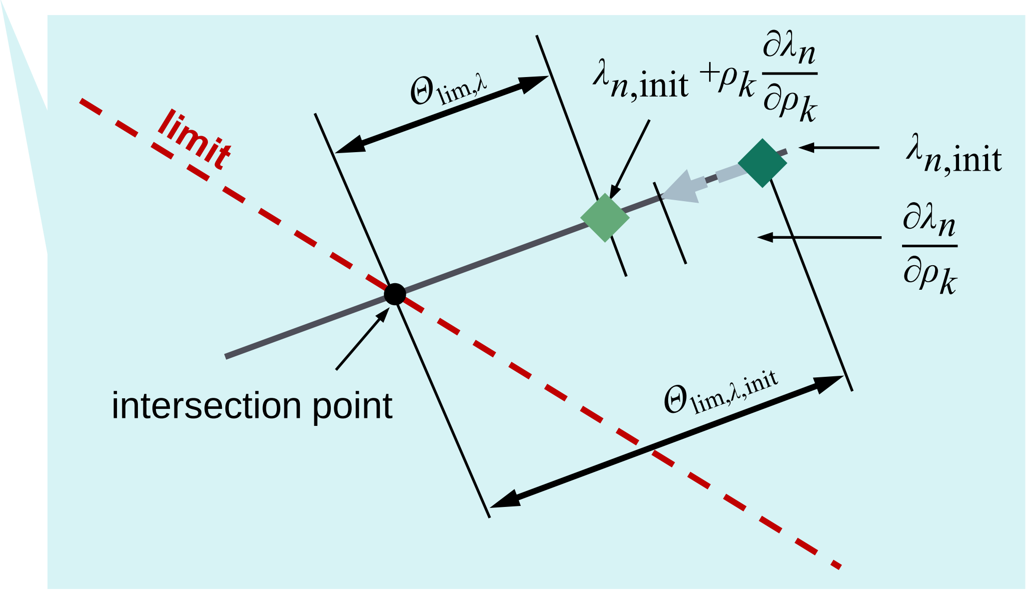
Stability-constrained operational optimization approaches

Combined consideration of stability issues in operational optimization

- Small signal stability considering Eigenvalue analysis
- Modelling approach for hybrid AC/DC power system optimization
- Consideration of critical Eigen-values and their sensitivities on controllable ("operational optimizationable") parameters in set point optimization







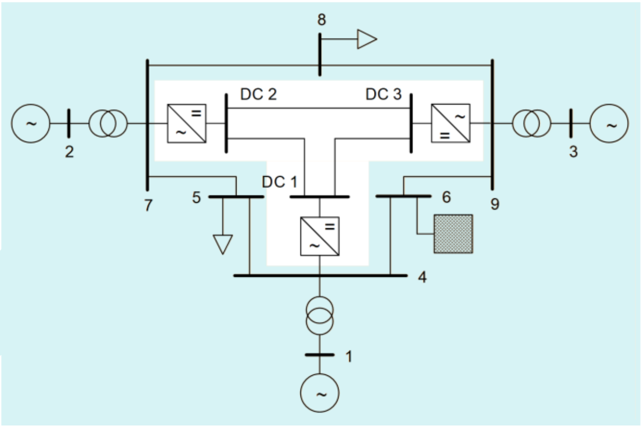
$$\min_{\boldsymbol{x}} f_{\mathrm{obj}}(\boldsymbol{x}) = \mu\left(\boldsymbol{x}_{k,\mathrm{set}} - \boldsymbol{x}_k\right) + \sigma \sum_{\lambda} h_\lambda \Theta_{\lim,\lambda} k_\lambda$$

- h_λ: Distance to limit
- k_λ: Eigenvalue sensitivity

See also: D. Mende et al.: ‚Combined optimization of steady-state operation and small-signal dynamics in hybrid AC/DC power systems', IEEE PES APPEEC, Melbourne/Online, 2022. DOI: 10.1109/APPEEC53445.2022.10072101..

Application examples

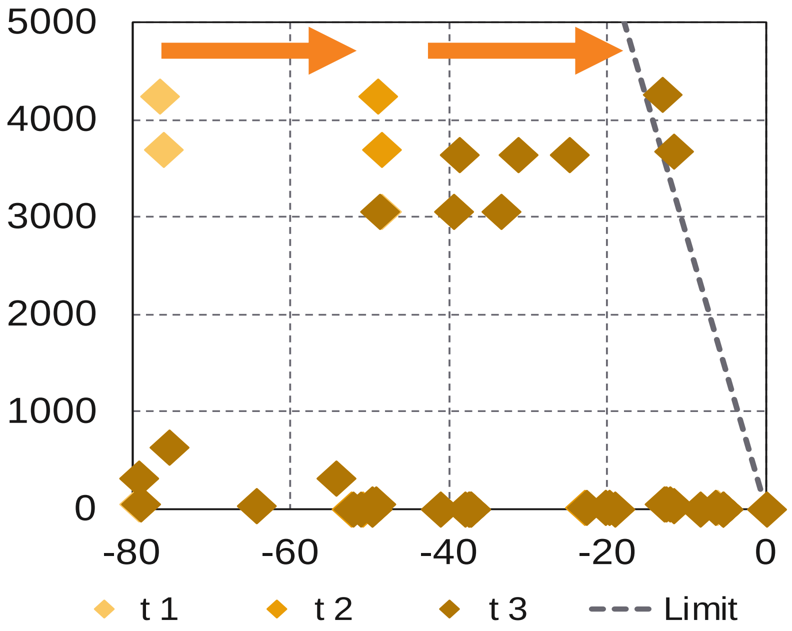
Stability-constrained optimization approaches

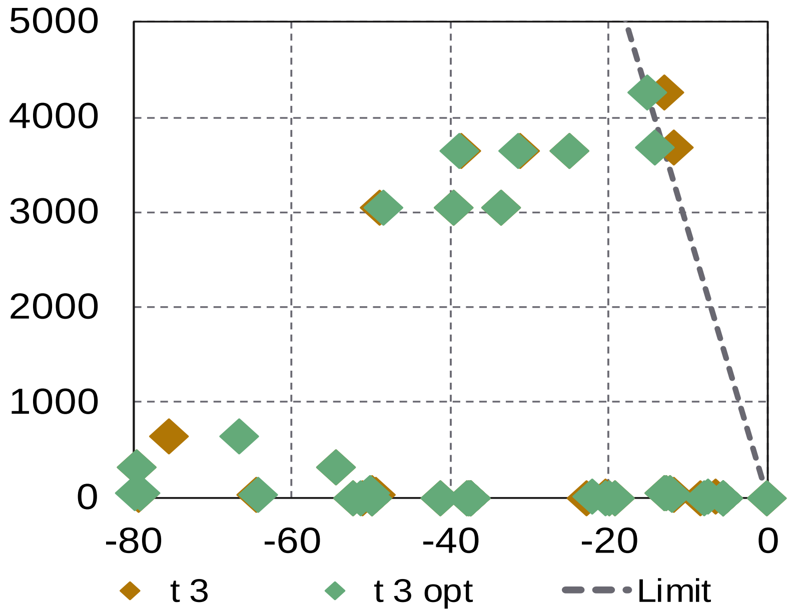


Combined consideration of stability issues in operational optimization

- Simulation example in small AC/(MT-)DC power system
- Time series simulation example leads to critical Eigenvalue constellation
- Optimization example shows adaption of operation points for HVDC converters to keep Eigen-values in desired area

▶ Hybrid AC/DC-system optimization allows to keep Eigenvalues within acceptable limits





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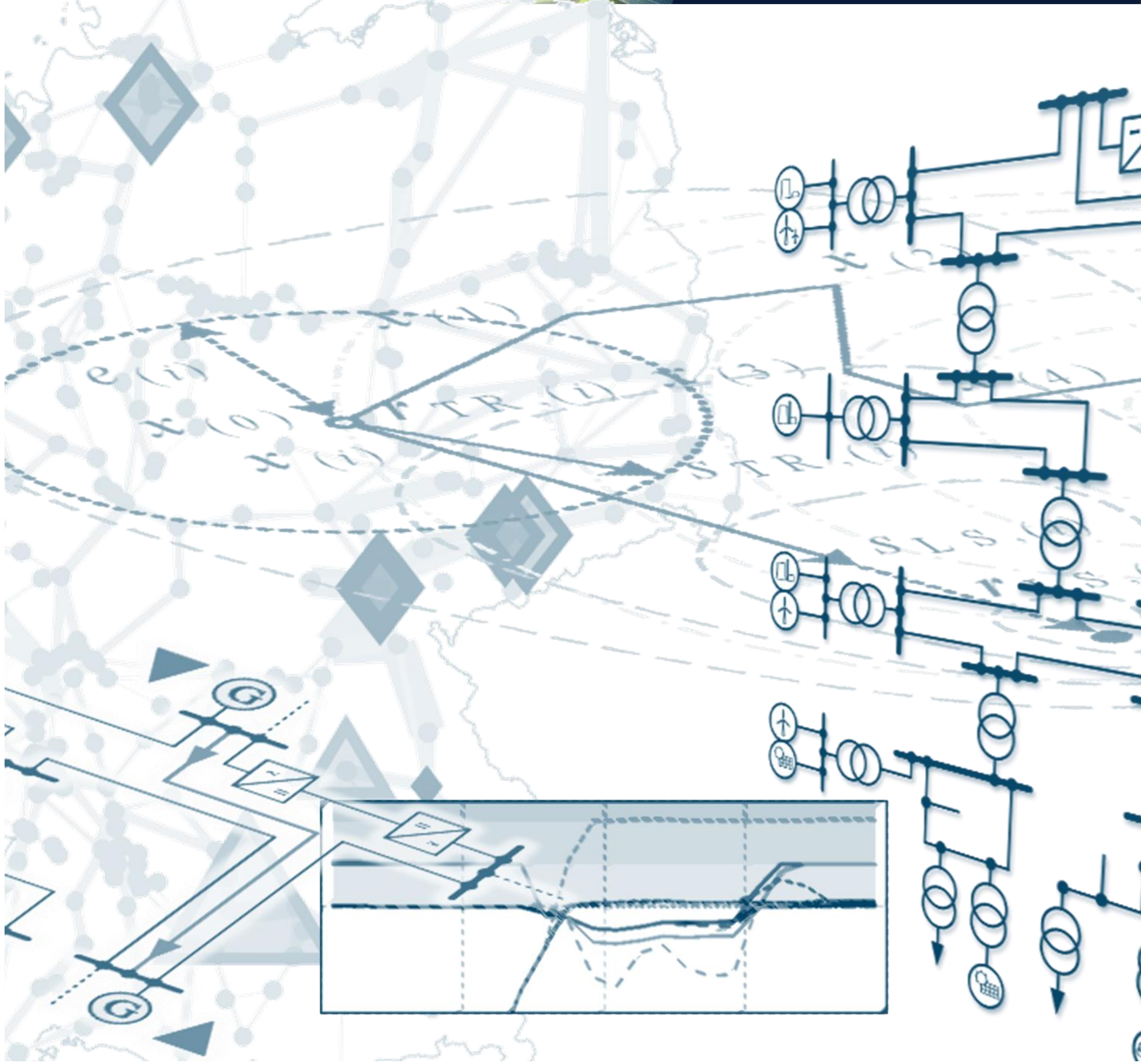

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Challenges and future tasks

All tools in grid operational planning and (real time) grid operation and need to support the system operators in the control room and therefore need

- their special acceptance,
- an intuitive operation and
- compehensible results

▶ **At the end, still the operator is responsible for the secure system operation, but optimization solutions can support!**

Nonlinearity
Power flow
Control schemes
Customer
…

MI-problems
Compensation devices
Tap Changer
Topology
…

Complexity & problem sizes
Number of ele-ments / variables
…

Fast decision making
Operational planning processes
Congestion management
…

Integration of AI-/ML-approaches
Combined solutions
Routines
…

Acceptance
Operator
Security
Robustness
…

Data integration
Interfaces / Conversion
Robustness
Completeness
…

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Thank you for your attention!

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