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Operational aspects of TSO-DSO coordination – Project ATTEST

Tomislav Capuder

tomislav.capuder@fer.hr

Karlo.sepetanc@fer.hr

31.1.2023.

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Introduction

- To unlock the flexibility of the distribution level users – TSO-DSO coordination in planning and *operation* is needed!
- Main areas of TSO-DSO coordination are:
  - Network planning an development,
  - Operational planning and real-time operation of (low carbon distributed) power system,
  - Market aspects/functions/products,
  - Balancing and imbalance settelment,
- TSO-DSO coordination concepts:
  - Centralized ancillary services market model
  - Local ancillary services market model
  - Shared balancing responsibility model
  - Common TSO-DSO ancillary services market model
  - Integrated flexibility market model

ATTEST TSO-DSO coordination approach

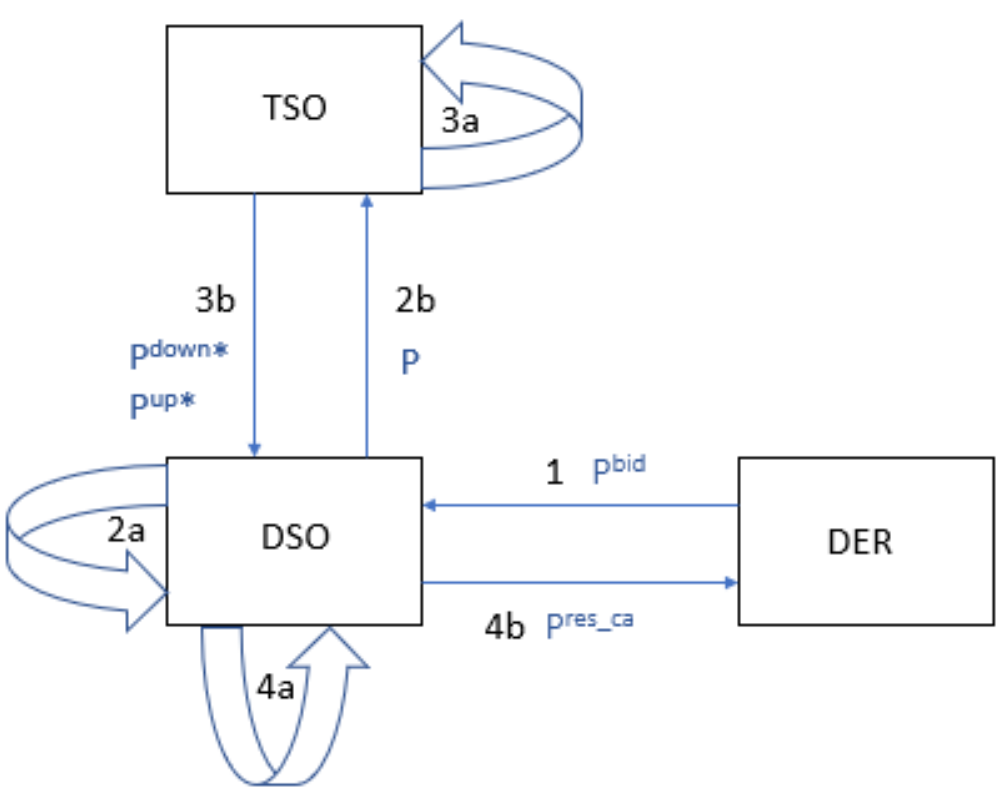
ATTEST TSO-DSO coordination approach

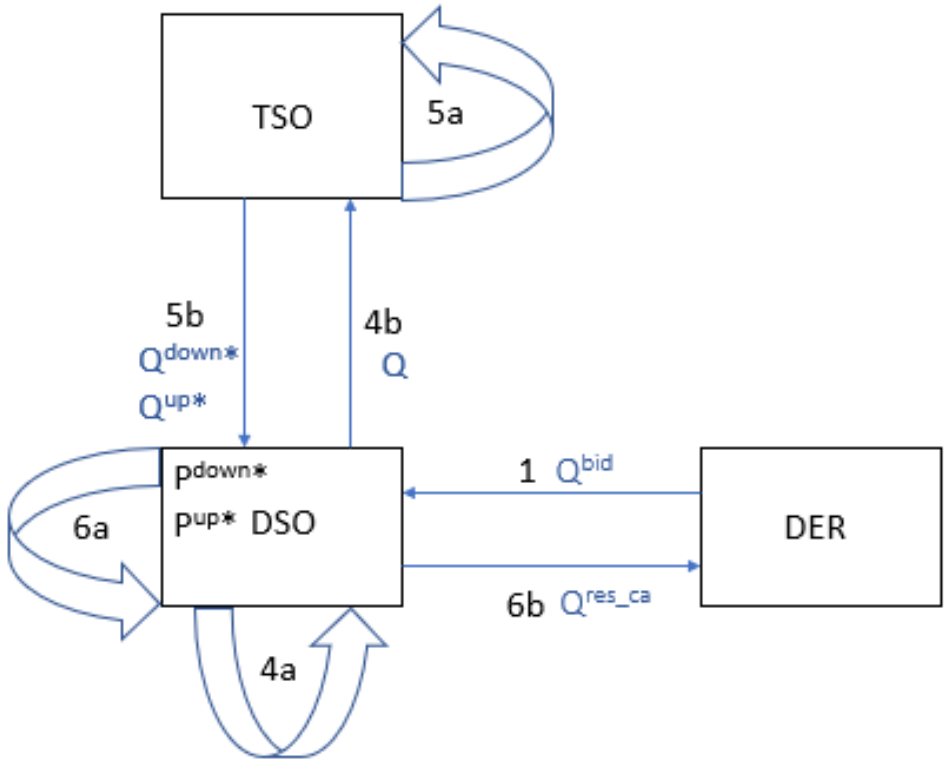
- Both TSO and DSO can use flexibility from DERs, but the TSO has the priority
- Non-optimal cost-wise for the DSO due to respecting agreed ancillary service schedule at the interface with the DSO
  - Should be remunerated by the TSO (to some extent)
- Secure and efficient distribution network operation because distribution constraints are considered in the market clearing
- Precise communication with high computational complexity
- Additional infrastructure for communication between system operators is required
- Divided in DA procurement phase and RT activation

Decoupled active and reactive power bids

- Due to complexity of pricing mechanism for the coupled active and reactive power bid
- DERs independently submit their active and reactive bids to the DSO with the constant cost per bided unit of energy
- DSO calculates the range of active and reactive power from submitted bids which does not violate network constraints and can, therefore, be offered to the TSO
  - First active power bids,
  - Then reactive power bids (having agreed/fixed active power exchange profile at the TSO-DSO interface).

Reservation of active and reactive power services at day-ahead operation planning





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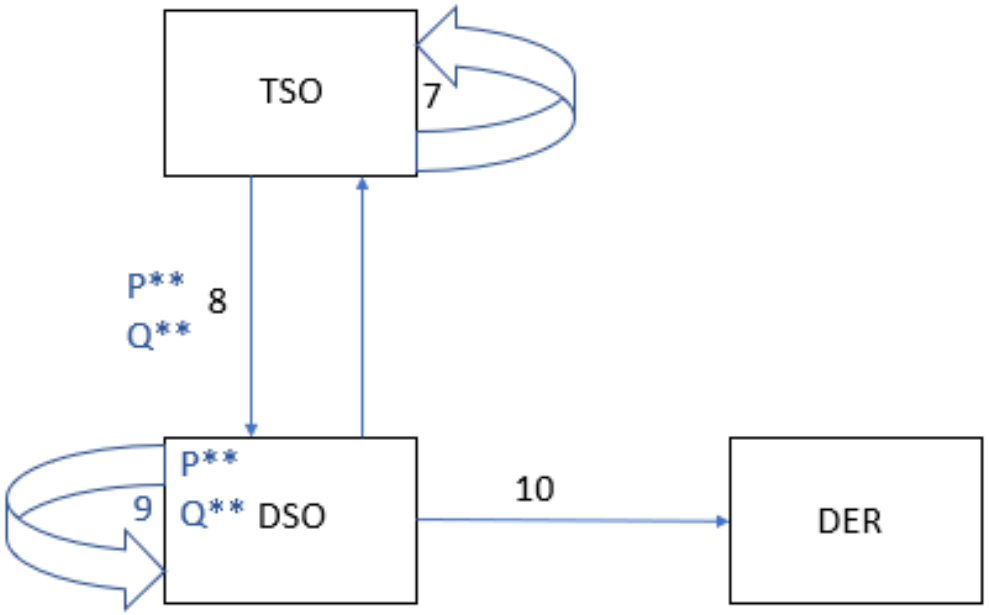
Activation of active and reactive power services in real-time operation



7. The TSO runs OPF in RT and determines the required ancillary service P** and Q**.

8. The TSO sends to the DSO the desired active power P** and reactive power Q**.

9. The DSO runs RT OPF with the fixed P** and Q** values at the TSO/DSO interface and clears the local RT market making sure to satisfy DG constraints.

10. The DSO activates flexibility providers.

Roles and responsibilities in grid operation and procurement

Roles in grid operation for ATTEST TSO/DSO coordination approach

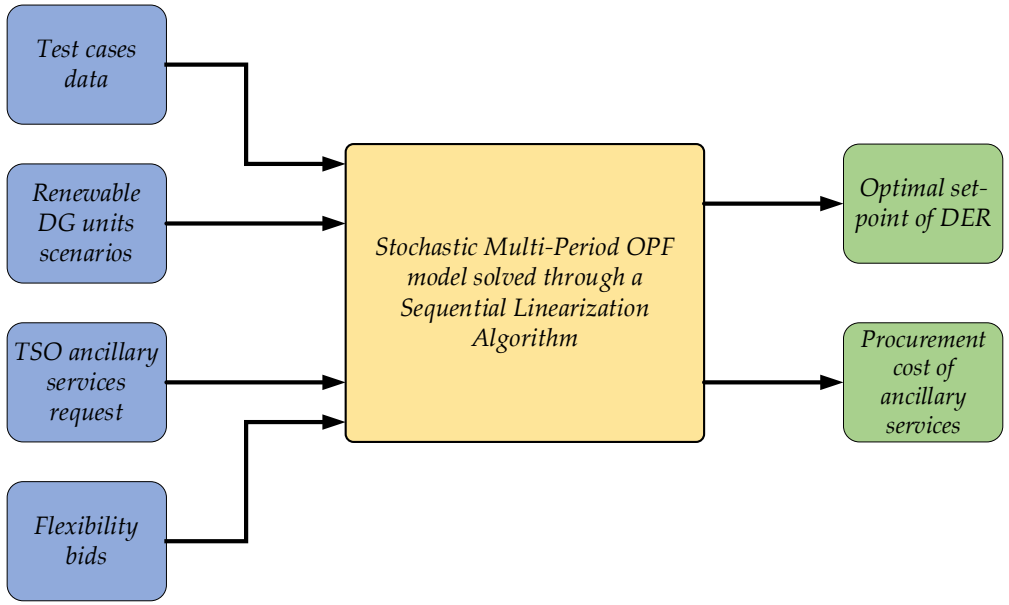
System Operator	System Balance Responsible	Data Manager
TSO (TG) DSO (DG)	TSO (TG; DG)	TSO (TG) DSO (DG)

Roles in ancillary services procurement in ATTEST TSO/DSO coordination approach

Reserve Allocator	Buyer	Seller	Aggregator	Market Operator
TSO (TG) DSO (DG)	TSO (TG; DG) DSO (DG)	CMP (TG; DG)	CMP (TG; DG) DSO (DG)	DSO TSO

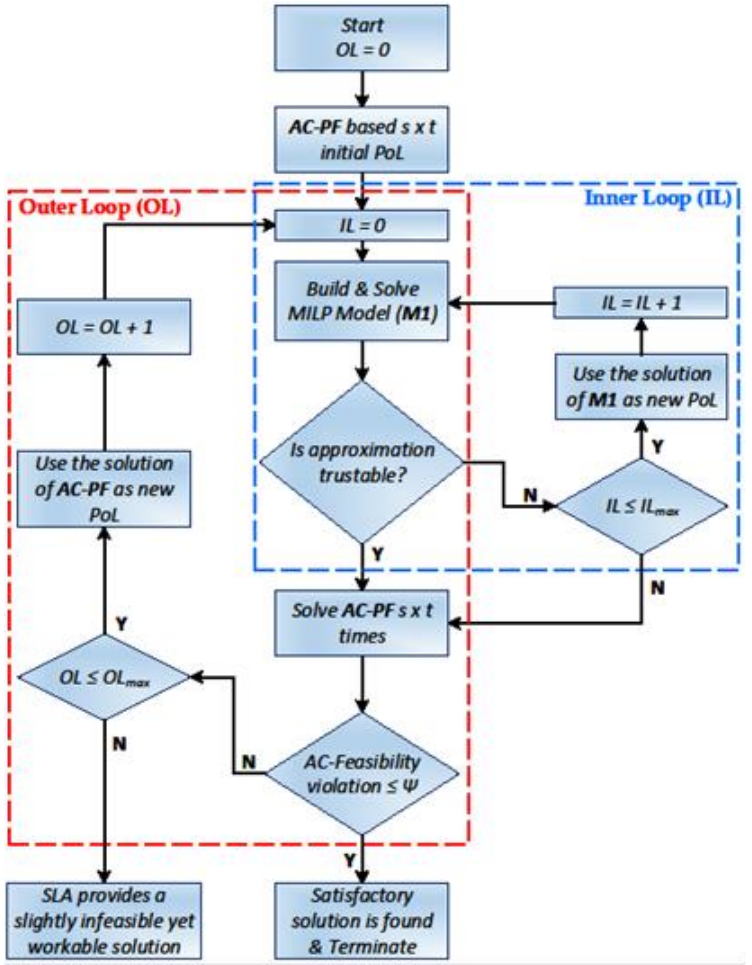
Tool for Ancillary Services Procurement in Day-Ahead Operation Planning of Distribution Networks

- Optimal flexibility scheduling of available DERs to support DSO in congestion management and voltage control on a 24-hour basis considering:
  - the uncertainty of RES units,
  - electrical energy storages (EES) and electric vehicles (EV),
  - aggregated flexibility of low-voltage systems at medium-voltage/low-voltage interface,
  - actions of network management controllers of medium-voltage grid and interaction with TSO.



Tool for Ancillary Services Procurement in Day-Ahead Operation Planning of Distribution Networks (2)

- TSO/DSO coordination mechanism defines the constraints which ensure that TSO and DSO do not procure conflicting ancillary services in the market
- Objective: minimization of the overall network operation cost
  - the cost required to re-dispatch the active and reactive power of DERs.
- Mathematical formulation:
  - a stochastic multi-period mixed-integer non-linear programming (MINLP) problem
    - solved with a novel tractable sequential linearization algorithm in an iterative manner – to ensure tractability as well as scalability for large problems



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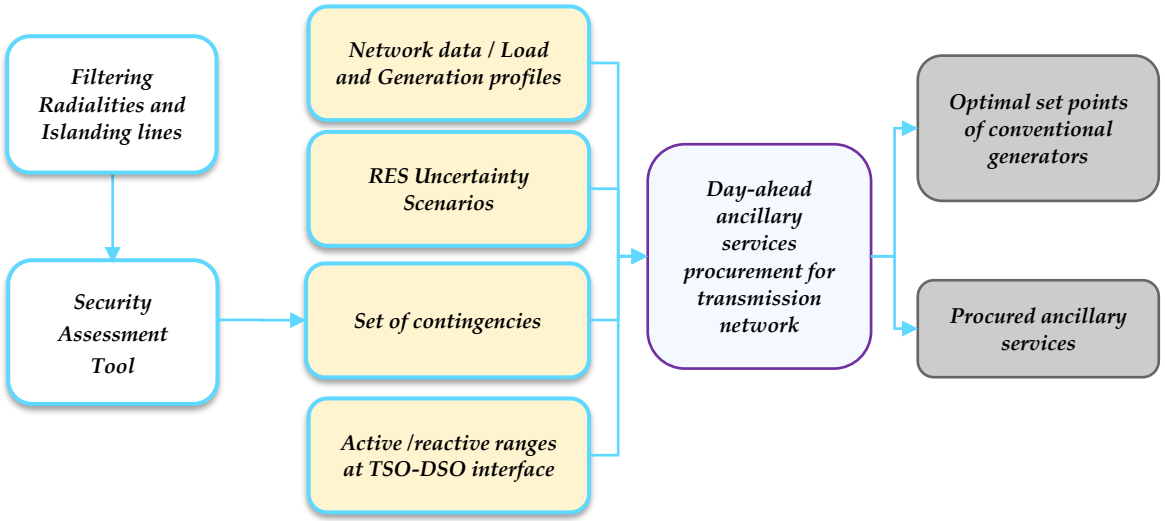
Tool for Ancillary Services Procurement in Day-Ahead Operation Planning of Transmission Networks

- Procurement of ancillary services for voltage control, congestion management and N-1 security criterion in day-ahead schedule considering:
  - a set of postulated contingencies,
  - the uncertainty of the renewables,
  - 24-hours ahead temporal interlinks to benefit from additional flexibility provided by EVs and ESS,
  - flexibility from conventional generators.
- Mathematical formulation:
  - a stochastic multi-period AC security

  constrained optimal power flow (S-MP-AC-SCOPF)
    - solved sequential linear algorithm in 3 stages

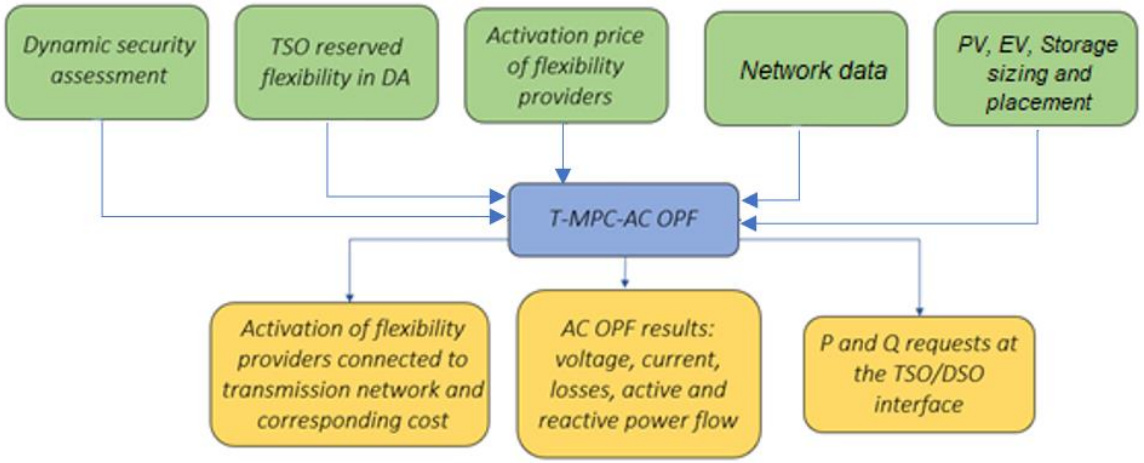


Tool for ancillary services activation in real-time operation of the transmission network

- Frequency control, congestion management, and voltage control in real-time operation of the transmission network
- The TSO calculates the volume and cost of activated AS based on the result of transmission level model predictive control AC OPF (T-MPC-AC OPF):
  - for each transmission level connected flexibility provider,
  - at the interface with the DSO.
- Model predictive control:
  - rolls every 5/15-minutes,
  - predicts the optimal reserve activation in order to solve transmission congestions and voltage problems,
  - makes decisions for the present time step considering future scenarios to potentially save available reserve resources for even more unfavorable near future.

Tool for ancillary services activation in real-time operation of the transmission network (2)

- Dynamic security assessment:
  - neural network data,
  - output : nadir and RoCoF values.
  - input control variables: total synchronous machine active power production, total inertia, total wind production and possible additional entries,
  - objective: keep these values within safe limits.



Tool for ancillary services activation in real-time operation of the distribution network

- Cost minimization of flexibility activation and penalties on constraints violations:

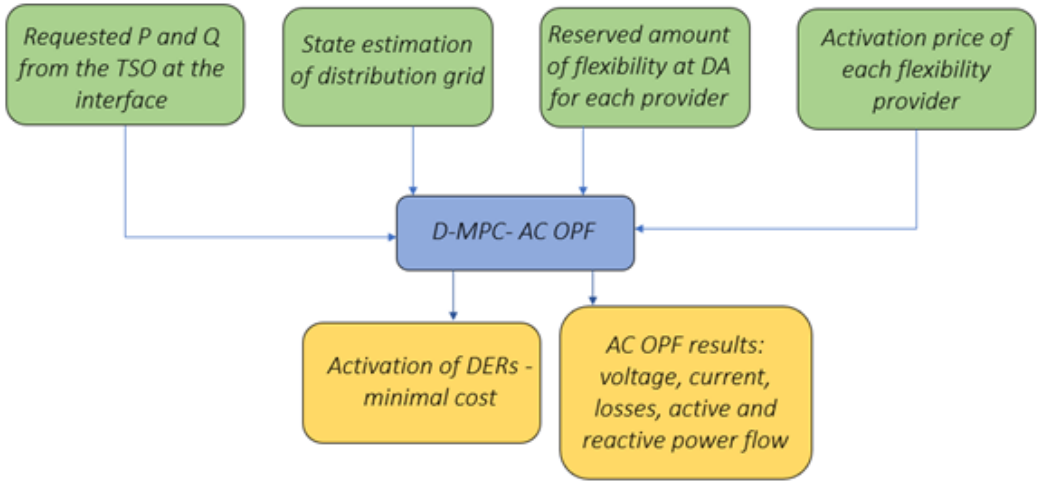
$$Min \sum_{t,dev,\frac{up}{dn}} c^{flex_{activation}} + \sum_{t,constr.} c^{pen}$$

- Decision variables considered in the optimization:
  - distributed generator down active power,
  - flexible loads up and down active power (EV),
  - storage up and down active and reactive power,
  - AC OPF constrained variables

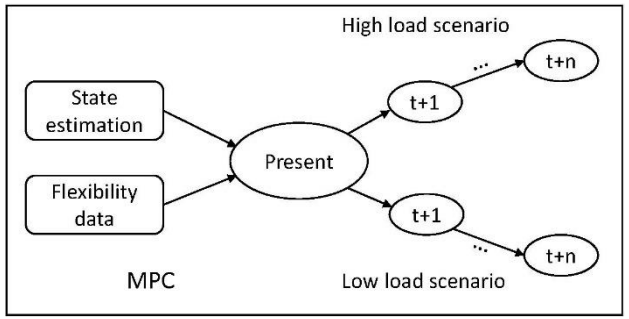
$$P_{ij} = e_i^2 G_{ij} + f_i^2 G_{ij} - e_i e_j G_{ij} + e_i f_j B_{ij} - f_i e_j B_{ij} - f_i f_j G_{ij}$$

$$Q_{ij} = -e_i^2 B_{ij} - f_j^2 B_{ij} + e_i e_j B_{ij} + e_i f_j G_{ij} - f_i e_j G_{ij} + f_i f_j B_{ij}$$

Tool for ancillary services activation in real-time operation of the distribution network (2)

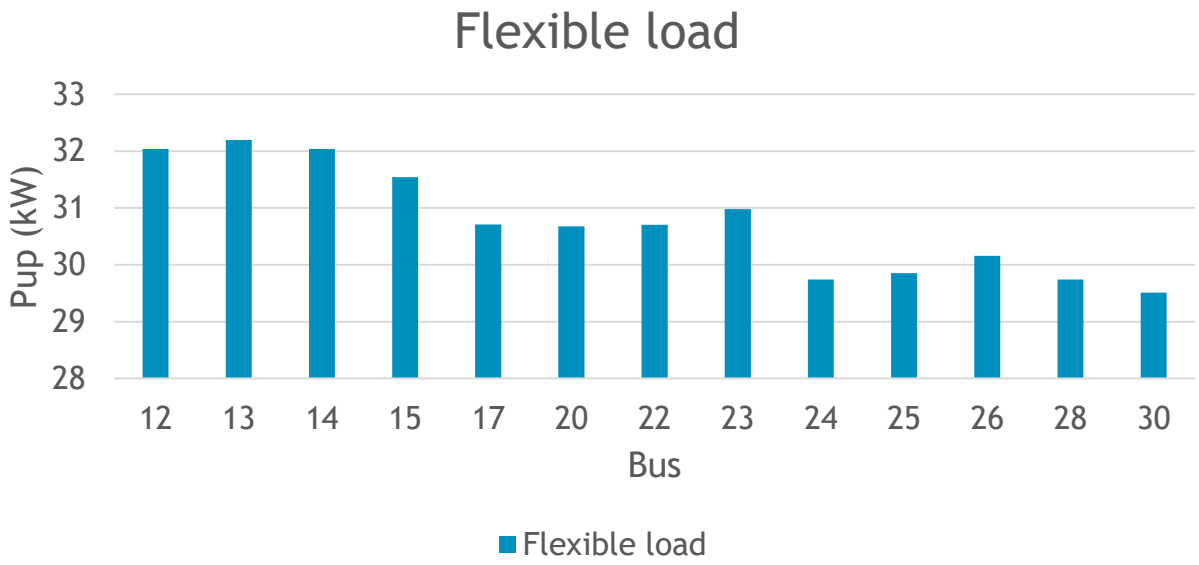


- Multi-temporal distribution level model predictive control AC OPF
  - High load scenario
  - Low load scenario



Distribution network real-time operation example

- TSO requesting 400 kW up power from DSO
- DSO selects devices to deliver 400 kW:



- DSO decreased reactive power for total 226 kvar from storages to deliver requested active power

Future steps

- Run simulations for 4 pilot locations (Croatia, Portugal, Spain, UK)
  - For 2030. enriched networks w/wth flexibility provision,
  - For 2040. enriched networks w/wth flexibility provision,
  - For 2050. enriched networks w/wth flexibility provision.

KPIs for technical, OPEX and environmental aspects

- Test the operational tools in Croatian demo live
  - RT data streaming from HOPS (Croatian TSO) and HEP ODS (Croatian DSO),
  - Running the tools and suggesting activation options,
  - Establishing KPI as benefits of a) activating flexibility, b) coordinating actions of two system operators

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