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Conceptual framework of the TSO/DSO coordination in ATTEST project

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Advanced **T**ools **T**owards cost-efficient decarbonisation of future reliable **E**nergy **S**ys**T**ems - **ATTEST**

- Starting date: March 2020
- Ending date: February 2023

- Portugal: INESC TEC
- UK: The University of Manchester
- Spain: Universidad Pontificia Comillas
- Luxemburg: LIST
- Italy: Softlab
- Croatia:
  - Končar-KET
  - HEP DSO
  - HOPS
  - ICENT

Vision & Objectives

Vision

To support the spread of knowledge and experience on a global scale, addressing the challenges of the energy systems of 2030 and beyond.

Objectives

To develop and operationalize an innovative open-source toolbox that integrates a set of optimization tools for operating, planning and managing assets in future energy systems.
To support transmission and distribution system operators in improving and coordinating their networks from a technical, economic and environmental standpoint.

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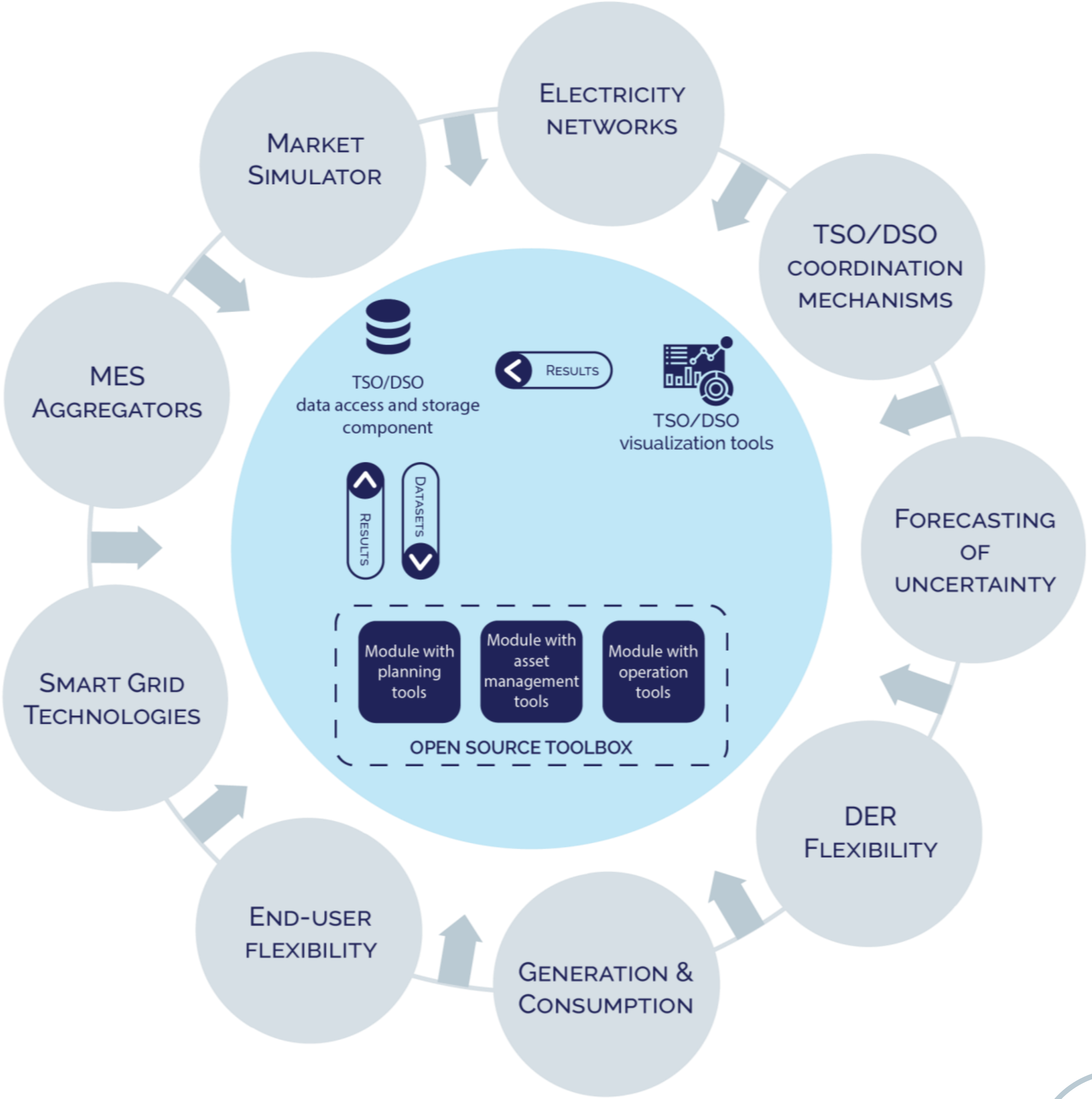
ATTEST concept

The open-source toolbox will be embedded into an ICT platform for TSO/DSO coordination that will provide data access connectors and converters, tools’ orchestration functionalities and visualization interfaces



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Introduction

- Package “Fit for 55”
  - 55% emissions reduction by 2030
  - Improving energy efficiency
  - 40% share of RES by 2030
- Additional flexibility in the power system is required – providing flexibility from DERs
- TSO used to be the only buyer of ancillary services
- Changes in distribution network operation and control
  - DSO involved in ancillary service procurement for local voltage control and congestion management
- Both system operators can participate in flexibility procurement
  - priority, type of service, roles

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Roles of System Operators

- Traditionally:
  - TSO – balancing services and non-frequency ancillary services provided from conventional power plants connected to the transmission network in order to ensure a secure, reliable and efficient electricity system operation
  - DSO – ‘*Fit and forget*’ approach without procurement of flexibility services
- Nowadays:
  - Active Distribution Network Management – the role of DSO is extended
  - DER used for provision of ancillary services to the TSO through connection points between transmission and distribution grid

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ATTEST TSO/DSO Coordination Approach

- ATTEST TSO/DSO coordination approach is divided in **day-ahead** and **real-time** operation
  - **Decoupled active and reactive bids** → provision of the service related to active and reactive power is part of one tool executed in two steps
  - Bids decoupling - due to **complexity of pricing mechanism**
- Hybrid coordination model with characteristics from
  - Centralized AS market model
  - Local AS market model
  - Shared balancing responsibility market model
- Non-optimal cost-wise for the DSO because the DSO needs to
  - meet operation constraints in distribution network,
  - meet an agreed ancillary service schedule with the TSO
- Calculation challenges
  - due to precise communication,
  - distribution network constraints in the market clearing approach
- Additional infrastructure investments for TSO-DSO communication
- Protentional problems with low market liquidity

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Grid Operation and AS Procurement in ATTEST project

- The TSO is responsible for balancing for the entire system, including both transmission and distribution
- Both TSO and DSO are responsible for their data management
- TSO determines required flexibility services for transmission network, while DSO determines for distribution network
- The TSO has the priority in flexibility services procurement

Reserve Allocator	Buyer	Seller	Aggregator	Market Operator
TSO (TN)	TSO (TN; DN)	CMP (TN; DN)	CMP (TN; DN)	DSO
DSO (DN)	DSO (DN)		DSO (DN)	TSO

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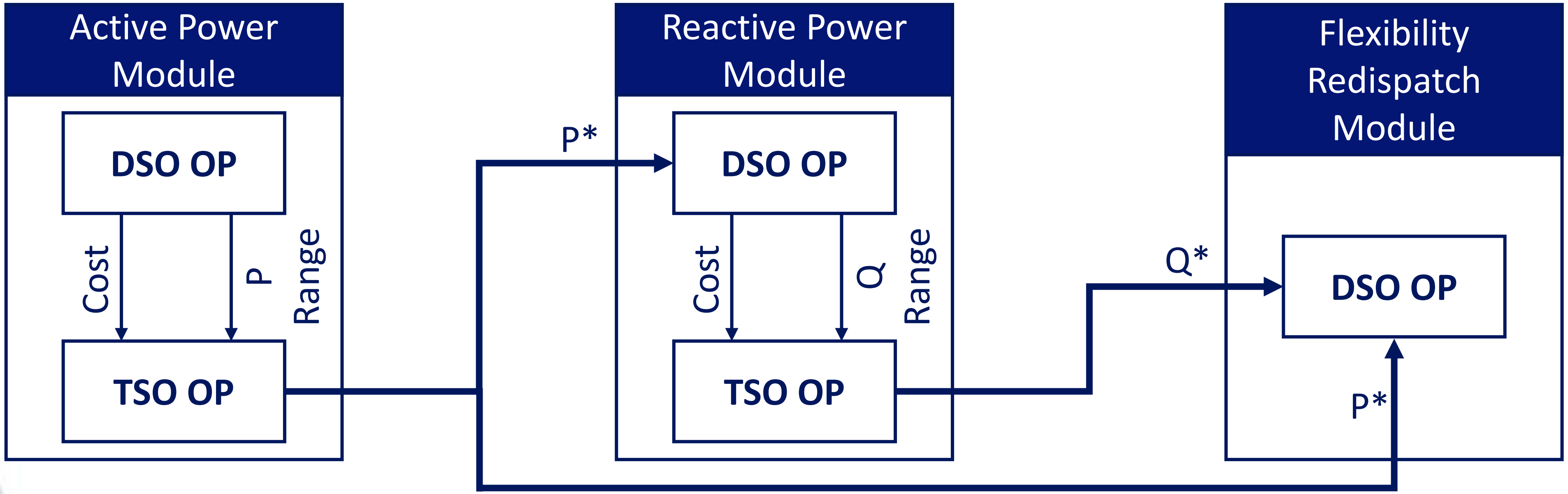
TSO-DSO Coordination Approach to Reserve Flexibility

- **Reservation of flexibility** in day-ahead operation Planning Problem ➡ **Decomposed AS Procurement**
- **Draw backs** of **Joint AS Procurement** through PQ charts
  - Determining cost of flexibility of each point of flexibility ➡ High computational burden
  - Cost signal needed ➡ Bid in TSO's AS markets
  - Integration of PQ map in TSO OP ➡ Still unknown



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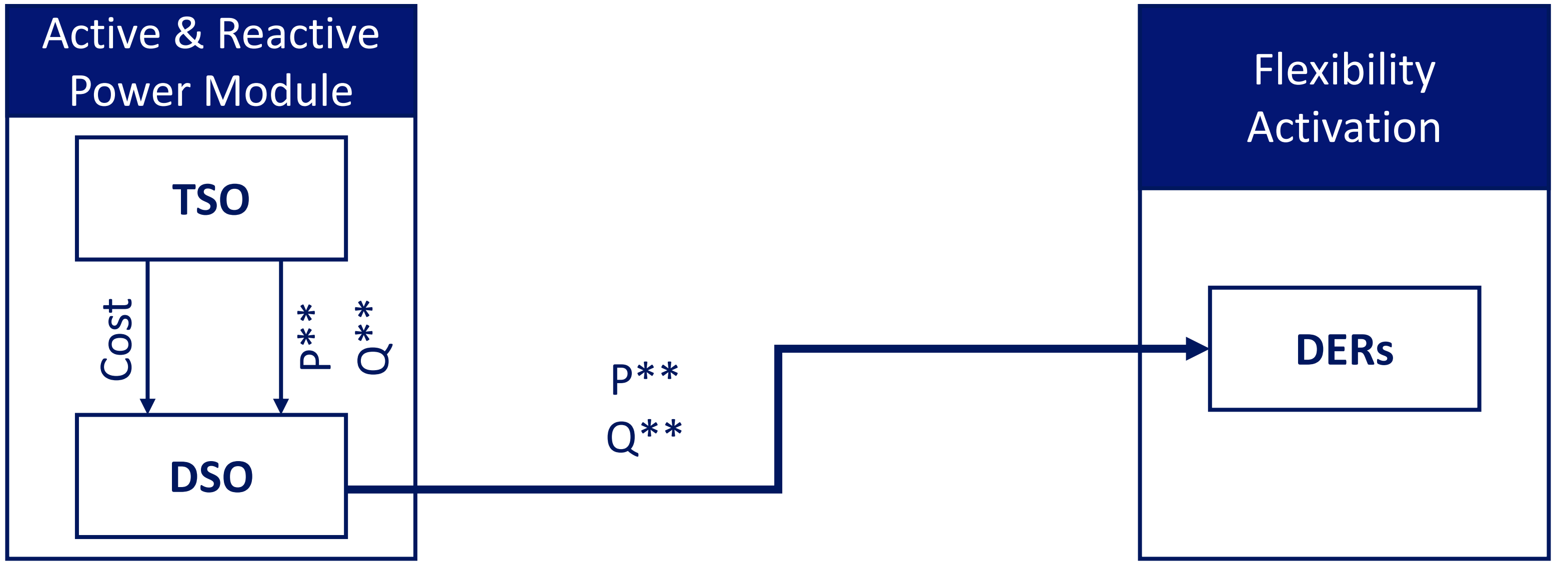
TSO-DSO Coordination Approach to Activate Flexibility

- **Activation of flexibility** in real-time operation ➡ **Coupled AS Activation**



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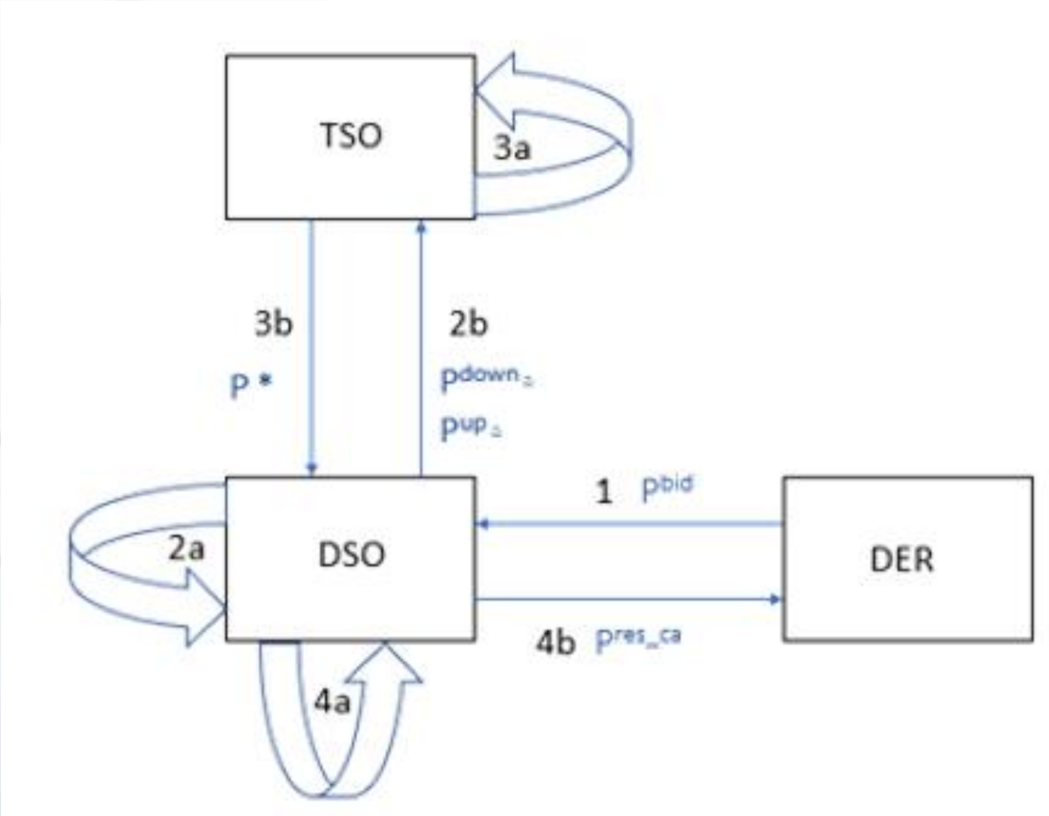
Reservation of Active Power Services at DA Operation Planning Stage



1) DERs submit their active power bids to the DSO divided in up and down bids with the corresponding cost.

2a) The DSO runs the AC OPF ensuring the distribution network constraints are met.

2b) The DSO submits active power flow range to global P market.

3a) The TSO runs the AC Security Constrained OPF to determine the required flexibility.

3b) The TSO sends to the DSO cleared bid P* either for upward Pup^* or downward $Pdown*$ reserved capacity of AS with the respect of P^{DA}.

4a) DSO clears the local market in order to optimize distribution network operation with the respect of agreed Pup^* or $Pdown^*$.

4b) DSO sends the request for active power capacity reservation to DERs.

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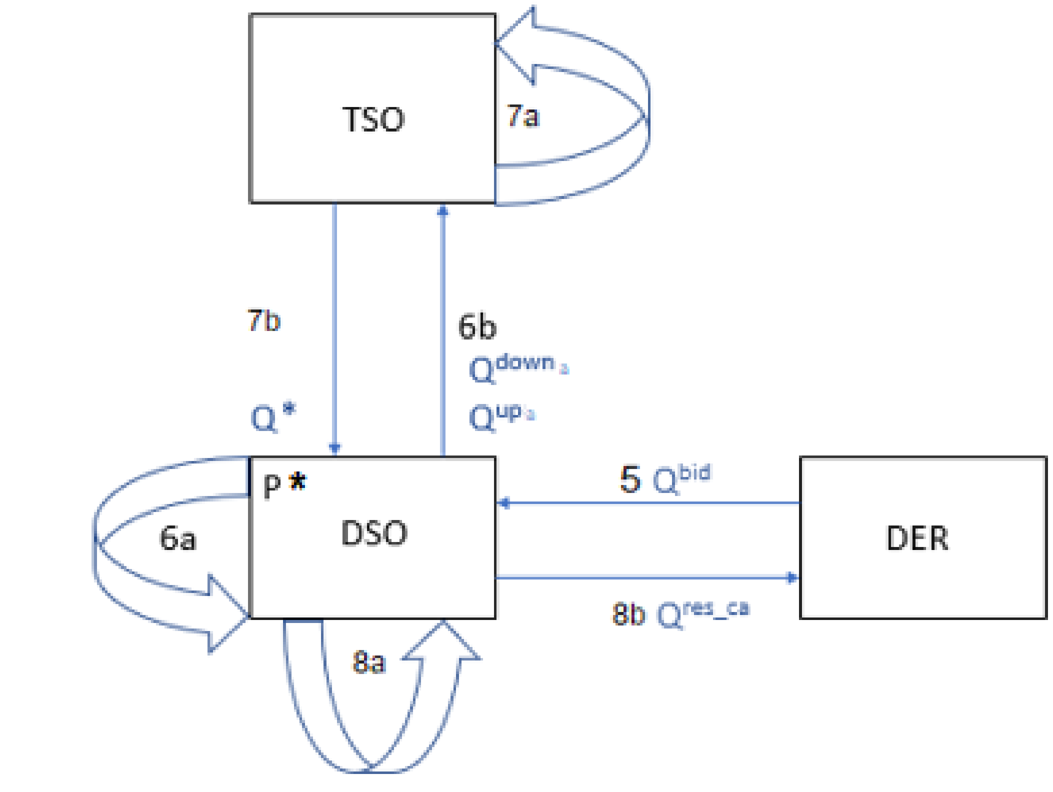
Reservation of Reactive Power Services at DA Operation Planning Stage



5) DERs submit their reactive bids to the DSO divided in up and down bids.

6a) The DSO runs AC OPF and determines Q flow range at TSO-DSO interface with fixed value of P^*.
6b) The DSO submits Q flow range bids capability to global Q market run by TSO.

7a) The TSO determines the required flexibility to satisfy voltage constraints.
7b) The TSO sends to the DSO cleared bid Q^* either for upward Qup^* or downard $Qdown^*$ regulation with the respect to Q^{DA}.

8a) DSO clears the local market in order to solve local problems with the respect of agreed P^* and Q^*.
8b) DSO sends the request for reactive power capacity reservation.

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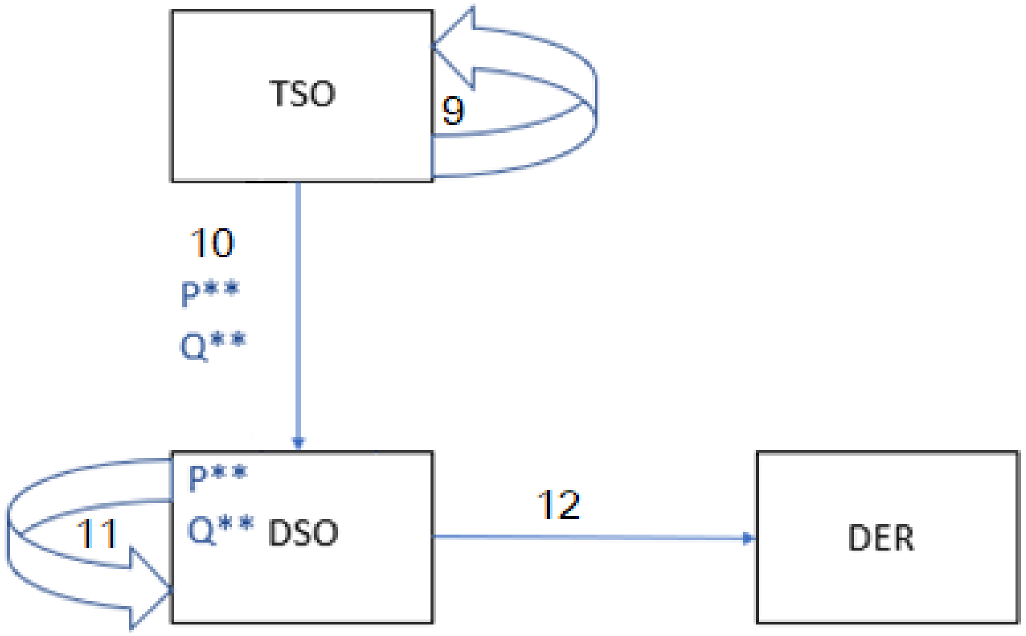
Activation of Active and Reactive Power Services in Real-time Operation



9) The TSO runs the SCOPF in RT and determines the required AS P^{**} and Q^{**} aiming to minimize the deviation from procured flexibility at DA stage.
Frequency security constraints will be integrated in the SCOPF formulation in a newly developed ATTEST tool for on-line dynamic security assessment.

10) The TSO sends to the DSO the desired active power P^{**} and reactive powerQ^{**}.

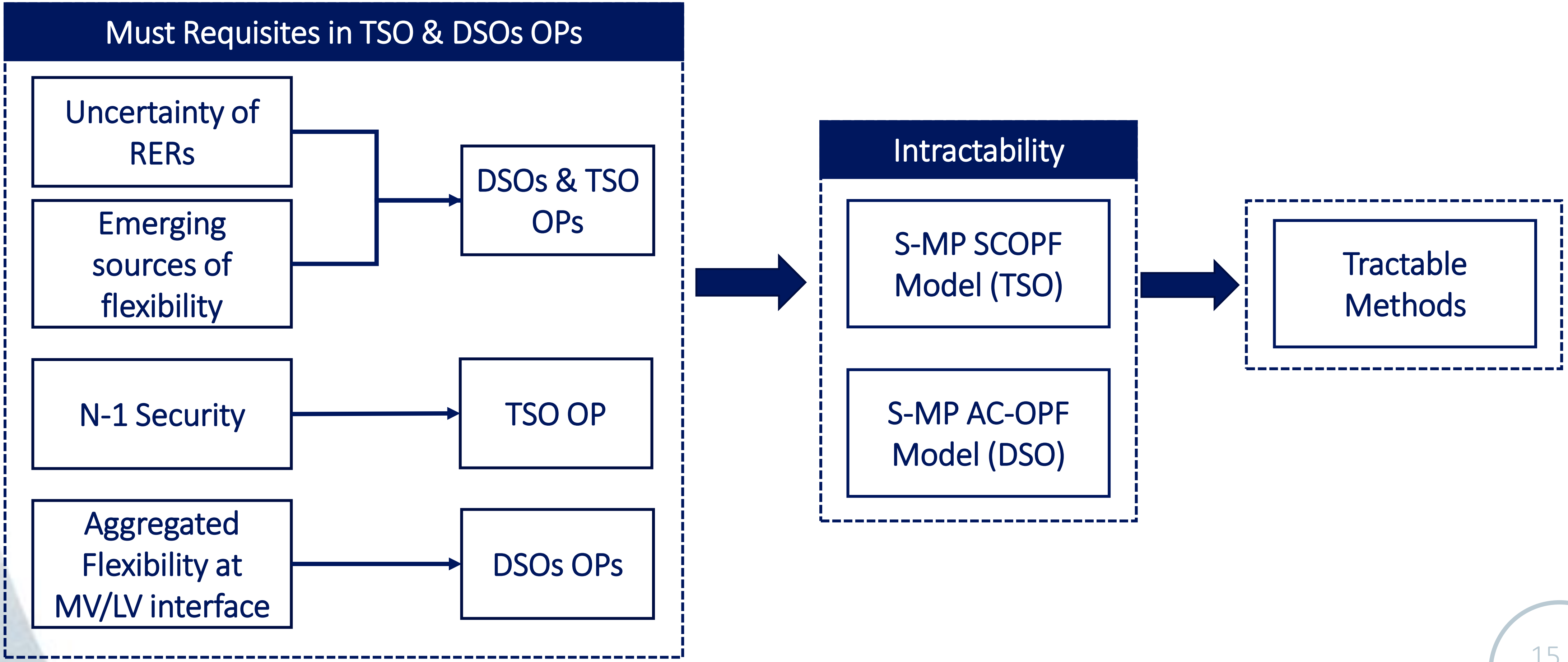
11) The DSO runs RT OPF with the fixed P^{**} and Q^{**} values at the TSO/DSO interface and clears the local RT market making sure to satisfy DG constraints.

12) The DSO sends signals to activate the flexibility providers / DERs.

Practical Requirements in DA Flexibility Procurement

Flexibility Procurement Optimization Problems (OPs) in Day-Ahead (DA) Operational Planning

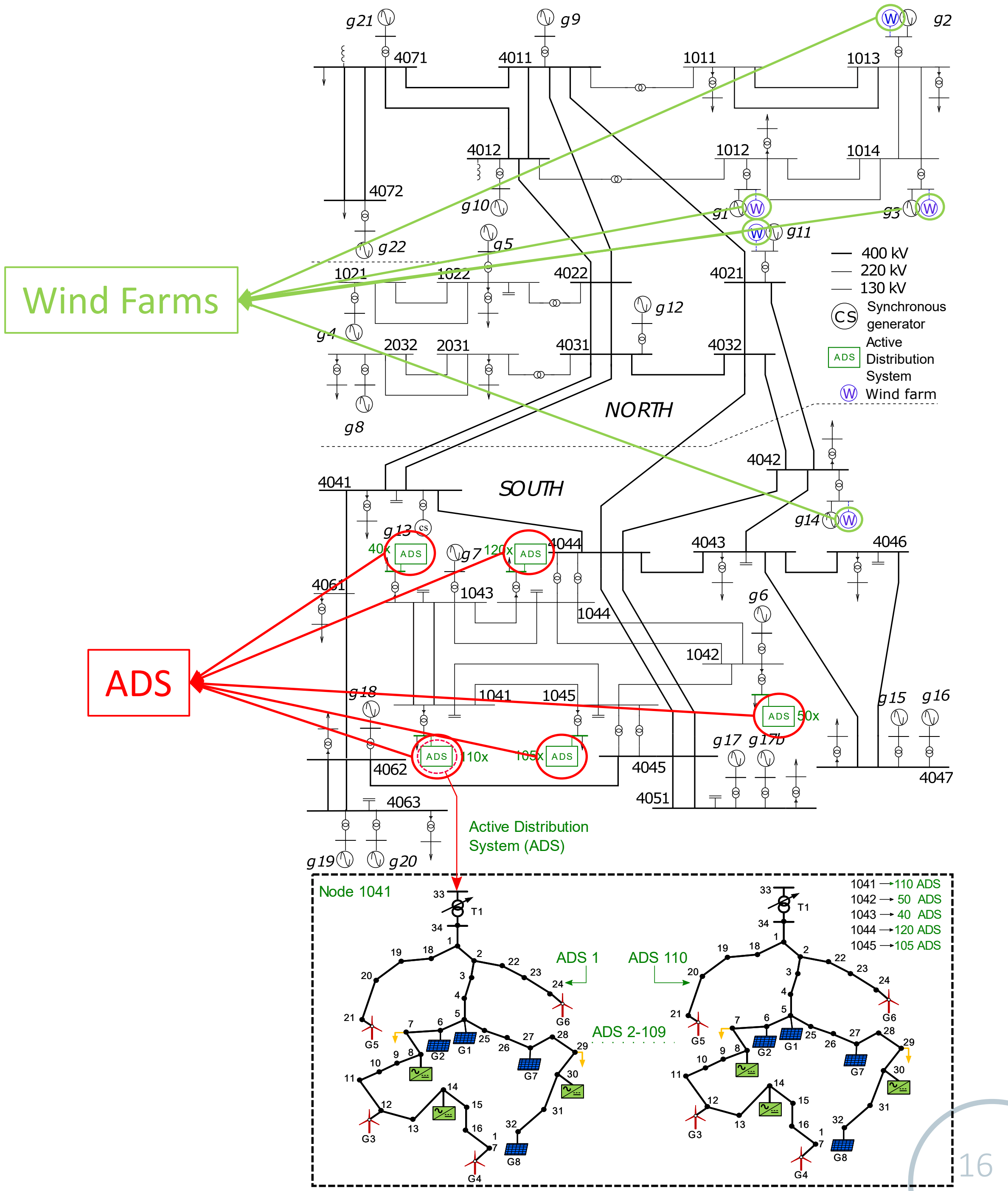
MUST consider:



Case Study

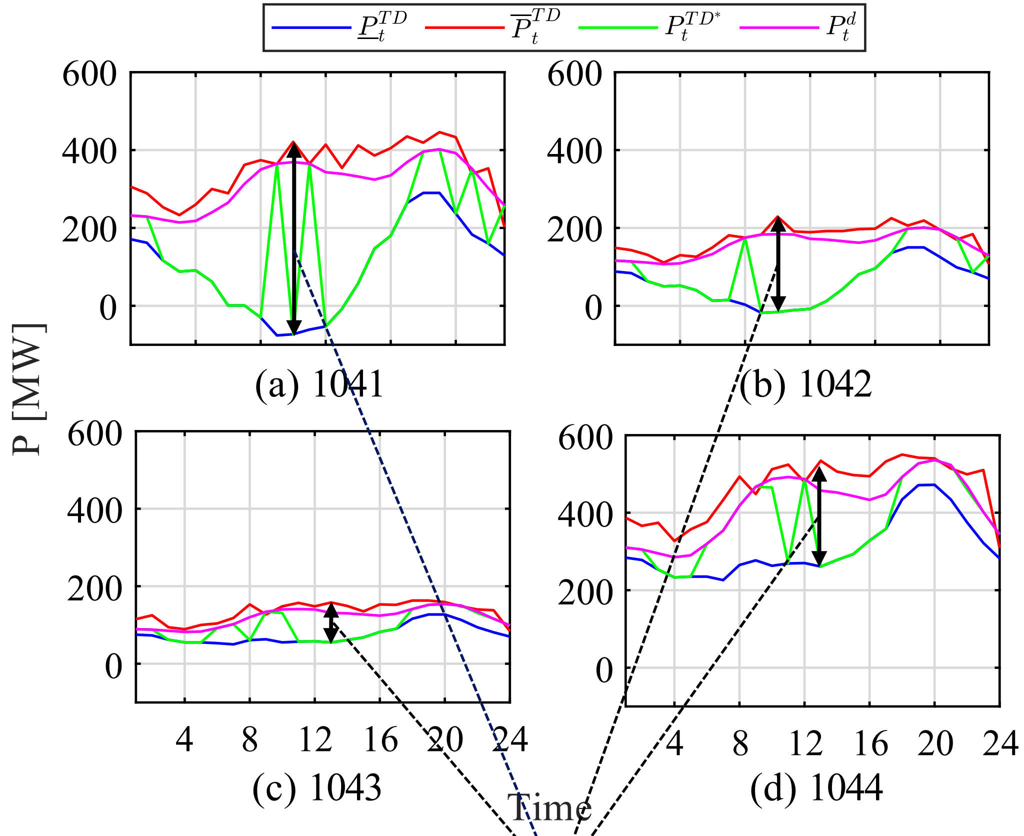
Proposed TSO-DSO coordination is tested on

- Nordic 60-bus transmission system (TS)
- Five **flexibility providing** active distribution system (ADS) at nodes 1041, 1042, 1043, 1044 & 1045
- 5 Wind farms in TS
- 33 N-1 line contingencies in TSO OP
- 4 Solar PV & 4 wind turbine DGs in ADS
- 3 EES & 2 FLs in ADS
- Reactive power provision from renewable DGs in ADS
- Flexibility is available in **SOUTH** & RES generation is in **NORTH**



Provision of Active Power Flexibility Range by DSO & Procurement of flexibility by TSO (Steps 1-3b)

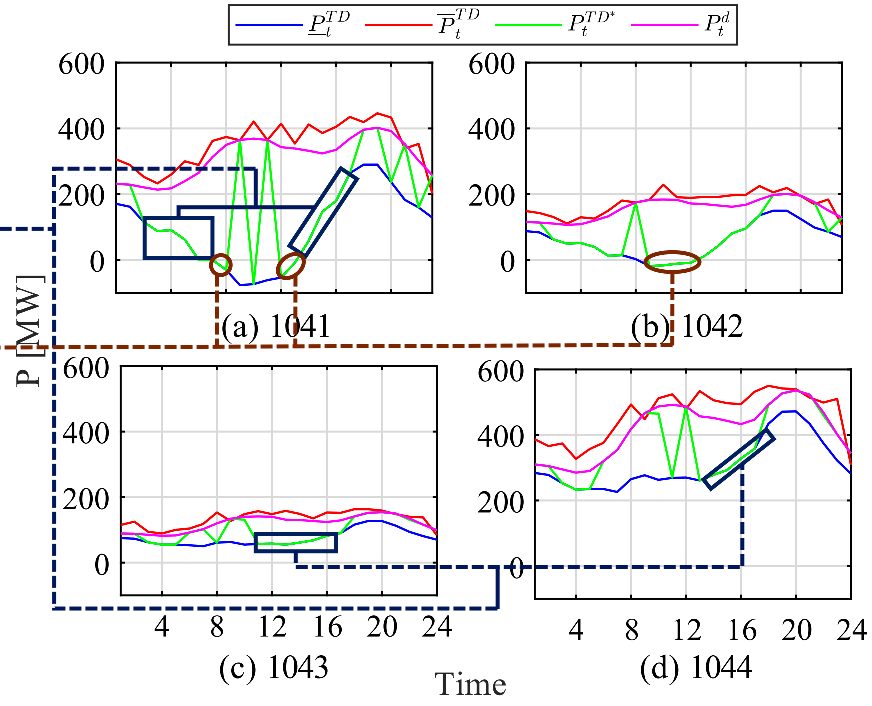
- Substantial amount of flexibility at each flexibility node
  - **Lower P bound 85 MW (1043) - 450 MW (1041)**
  - **Upper P bound 30 MW (1043) – 110 MW (1044)**
- Width of flexibility band varies at each flexibility node
  ➡ real world scenario
- Shape of flexibility band ➡ RES production profile
- DSOs at nodes 1041 & 1042 ➡ bi-directional power flow
- DSOs at nodes 1043 & 1044 ➡ uni-directional power flow



Maximum available flexibility at each node

Provision of Active Power Flexibility Range by DSO & Procurement of flexibility by TSO Cont'd (Steps 1-3b)

- TSO procures flexibility power range ➡ lower bound of active
  - **Reduces the power flow from TSO-DSO to relieve congestions in the TS; 3% reduction in congestion**
- Procured flexibility varies at each node
- Procurement of flexibility reduces the total operational cost
  - **Reverse power flow from ADS to TS**



COST (€) OF ACTIVATION OF ADSS FLEXIBILITY BY TSO

	Without Activated Flex.	Activated Flex.
Operation	151,145	141,437
Normal Gen. curt.	18,425	18,375
Post-contin. Gen. curt.	29,784	29,753
Flexibility	–	3,268
Total cost	199,354	192,833
Elapsed time (s)	2,445	2,449

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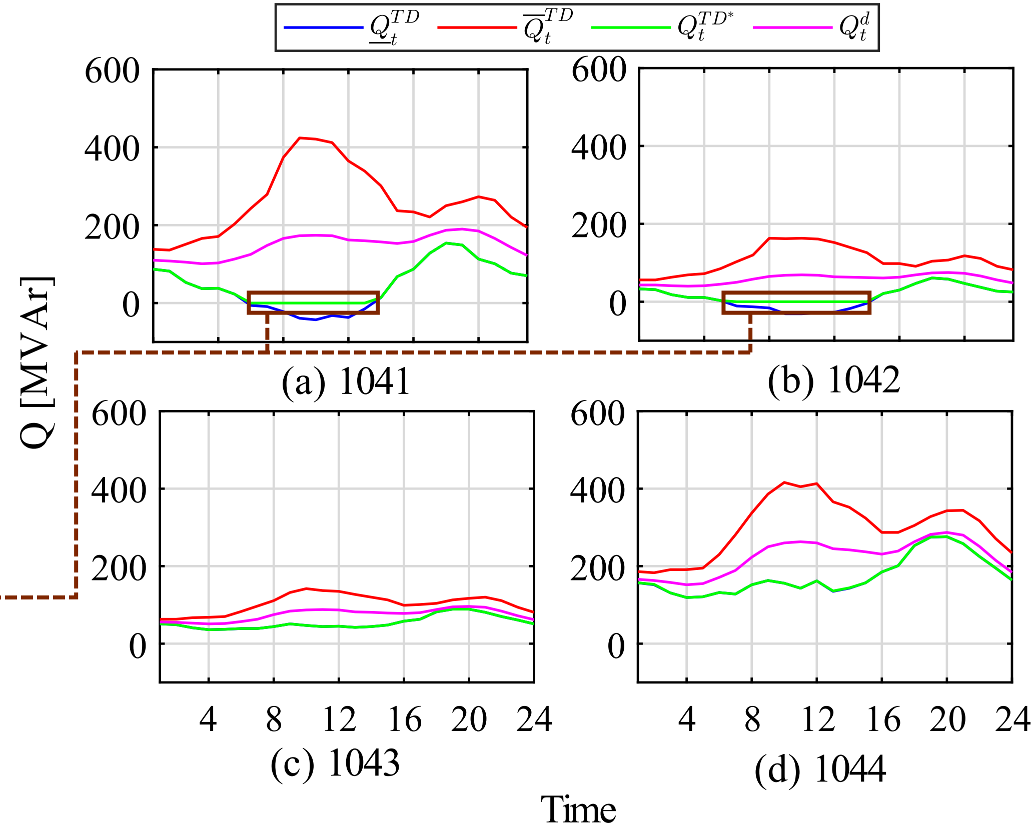
Provision of Reactive Power Flexibility range by DSO & Procurement of flexibility by TSO (Steps 5-7b)

- Substantial amount of flexibility at each flexibility node
  - **Lower P bound 44 MVAr (1043) - 211 MVAr (1041)**
  - **Upper P bound 55 MVAr (1043) – 252 MVAr (1041)**
- More uniform distribution around reactive power demand → more freedom during ‘over-voltage’ & ‘under-voltage’ scenarios
- TSO only procures the **positive** reactive power flexibility at all nodes
  - **Reactive power import at 1041 & 1042 becomes zero during 6h-14h**
  - **High cost of imported reactive power from ADS**
- Reactive power availability alone from conventional generator → Infeasible operation of TS
  - **Voltage limit is not met for some contingencies**



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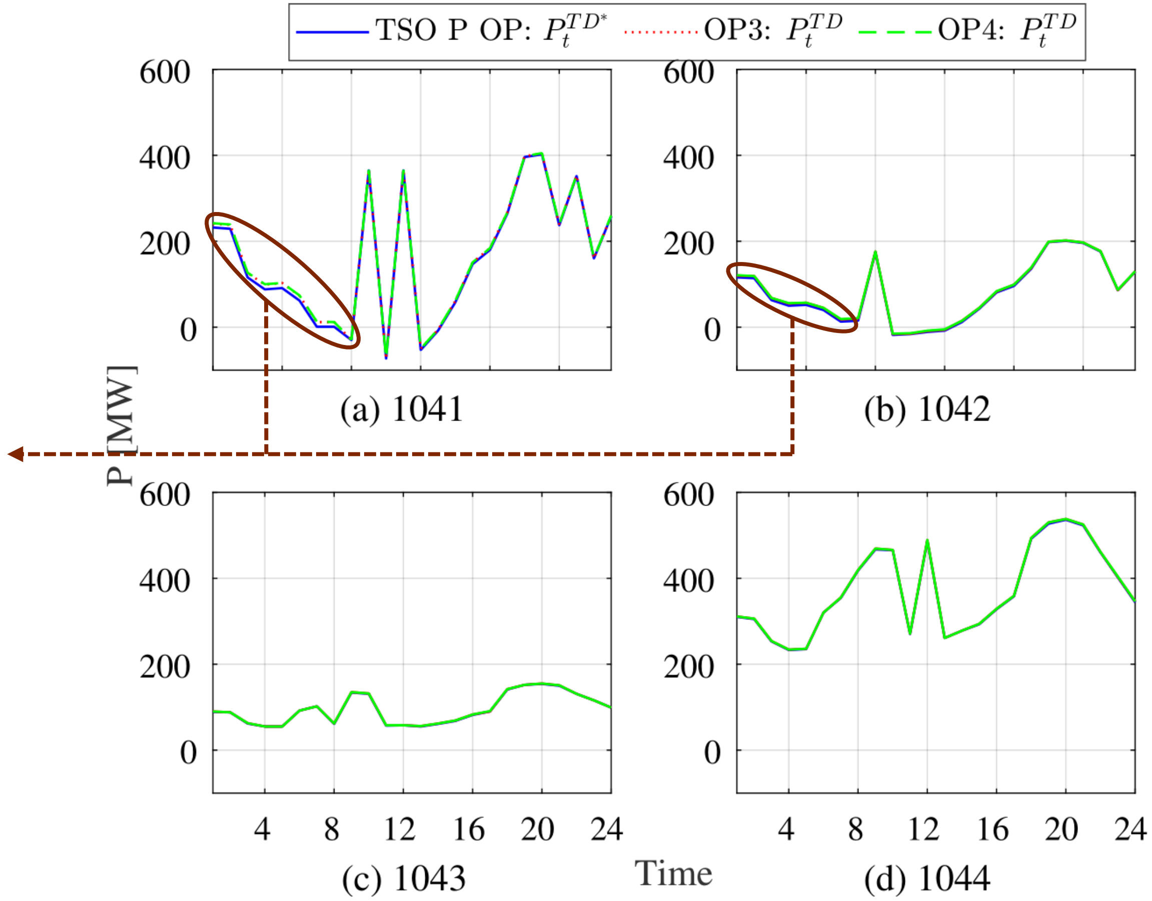
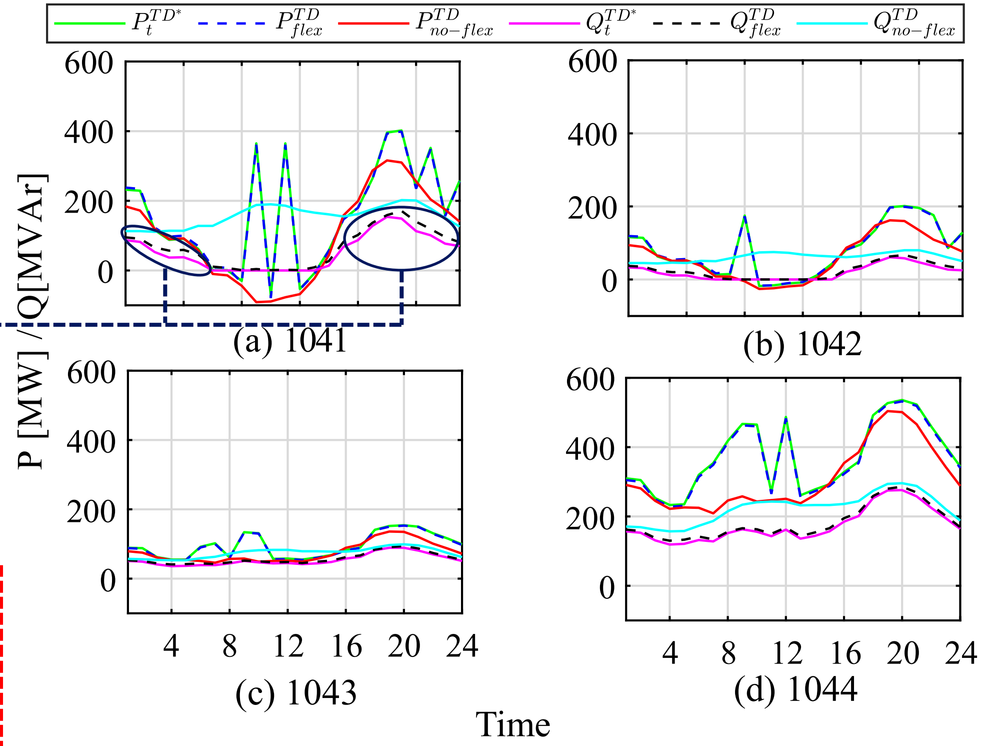
Provision of Reactive Power Flexibility range by DSO & Procurement of flexibility by TSO cont'd (Steps 5-7b)

- Committed active power MUST be respected at TSO-DSO interface while providing reactive power
  - DSO reactive power OP remains feasible
  - No obligation to fulfil the agreement under stressed operating conditions
- Active power deviates slightly during time-periods 1h-8h at nodes 1041 & 1042
- No active power deviation at nodes 1043 & 1044



Optimal Re-Dispatch of Active and Reactive Power by DSO (Steps 8a-8b)

- Active power deviation is negligible
- Reactive power **deviates** to some extent; deviation is not significant
- Major cost comes from the curtailment of active power
  - **Active and reactive power deviation penalty cost is small**
- No operational cost is associated under **no agreement** of active & reactive power flow at TSO-DSO interface

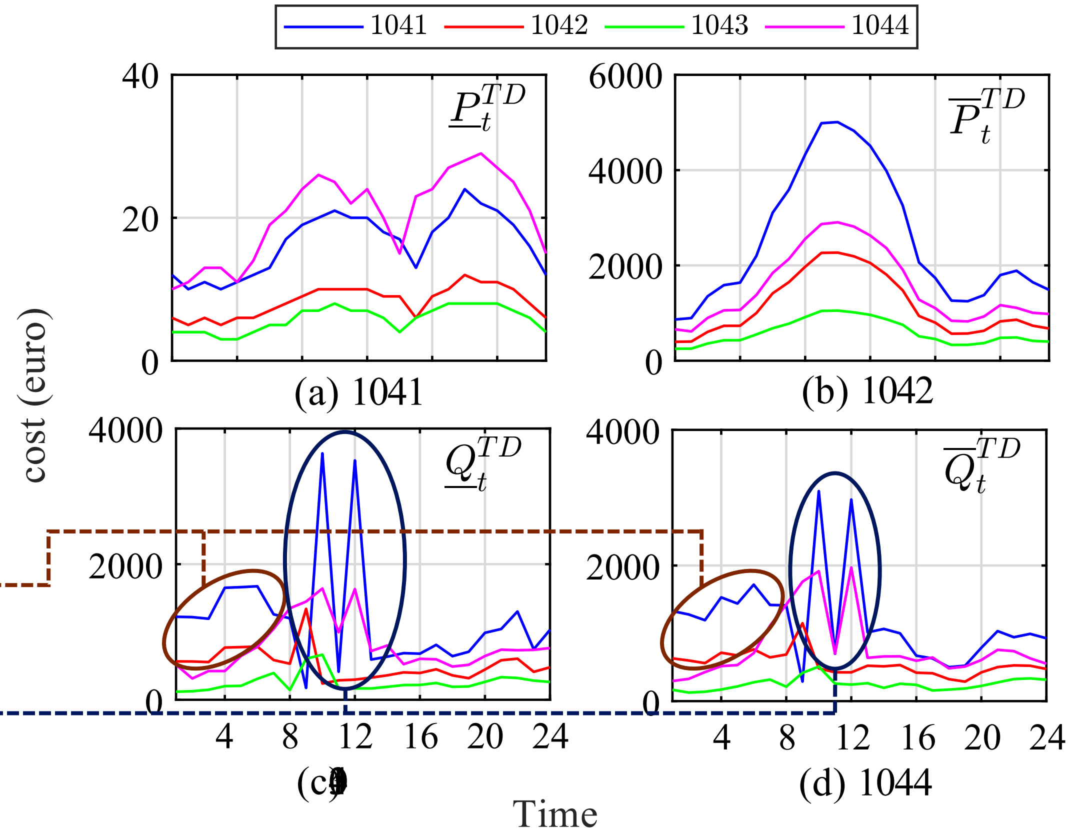


OPTIMAL DSO RE-DISPATCH MODULE RESULTS

Flexibility Nodes	With TSO-DSO flexibility			Without TSO-DSO flexibility		
	Cost (€)	P_{curt} (MW)	Time (s)	Cost (€)	P_{curt} (MW)	Time (s)
1041	271.7	12.4	386.7	0.00037	1.11×10^{-5}	27.4
1042	235.4	9.77	470.6	0.00037	1.11×10^{-5}	27.2
1043	157.3	10.14	198.9	0.00037	1.11×10^{-5}	27.7
1044	138.5	10.63	837	0.06217	1.11×10^{-5}	26.7

Cost of Active & Reactive Power Flexibility

- Lower active power flexibility bound ➡ Low cost
  - **No active power is curtailed**
- Upper active power flexibility bound ➡ High cost
  - **Full active power is curtailed**
- Lower & Upper reactive power flexibility ➡ Almost identical cost
- Q_{cost} = Re-dispatch $_{cost}$ + Violation of commitment $_{cost}$
  - **1h-6h, violation cost term dominates**
  - **8h-14h, re-dispatch cost dominates**



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RT Tools Description

What it does	How	Input
Minimize reserve activation	DR models	Flexibility data † / Flexibility DA schedule
Ensure network feasibility	AC OPF	Network data † / RT state estimation †
Ensure N-1 network security*	RoCoF and nadir NN in opt.*	NN parameters*
Address uncertainty	Stochastic MPC	Load scaling and penalty factors

* TSO only

† Common MATPOWER format

Optimization model

AC OPF		
Optimize OF	➡	minimize DA flexibility deviance
s.t.		
➢ bus balance		
➢ power flow equations	➡	rectangular formulation
➢ voltage limits		
➢ line thermal limits		
➢ device limits	➡	DR models
extra:		
➢ nadir and RoCoF neural network	➡	N-1 security
➢ time dimension	}	uncertainty – stochastic MPC
➢ load scaling		
➢ const. violation penalization		
DSO only:		
➢ satisfy (≥) TSO reserve activation		

Stochastic MPC

MPC:

- Time steps – 1 present and several close future

Stochastic:

- Low and high future load scenarios
  - progressively increasing uncertainty – load scaling factors
- Constraint deviation penalty factors

Effect:

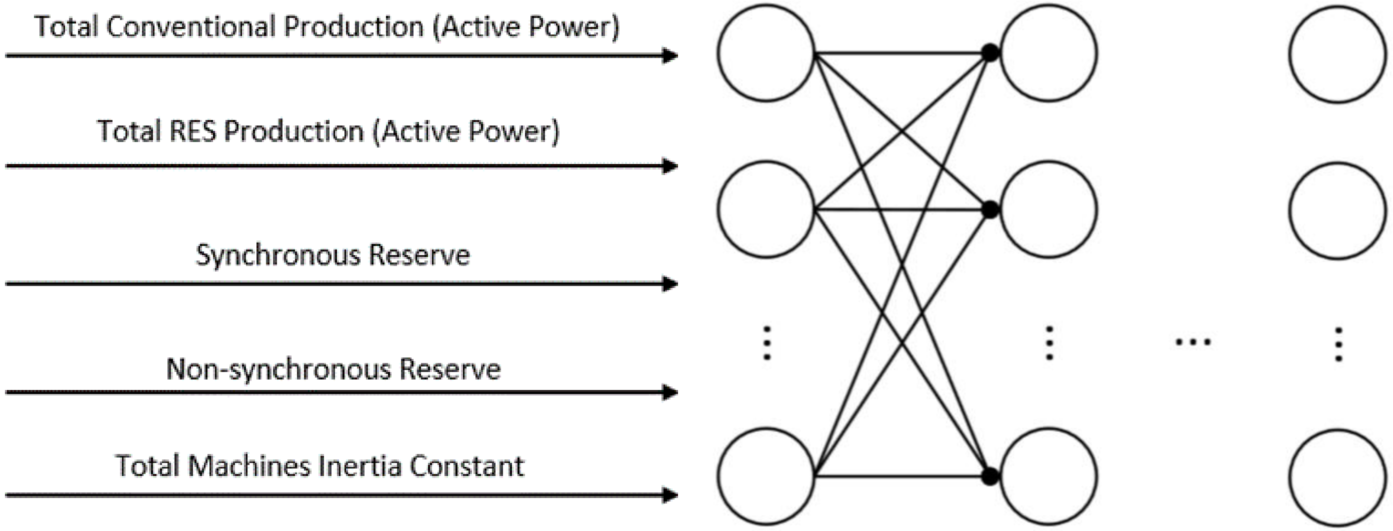
- Model feasibility robustness

Neural network as a constraint

- **Substitution principle:**
  - only 1 constraint needed per output

Input

Output



$$f_1(input) \quad = \quad Nadir \quad \leq \quad MAX\_Nadir$$

$$f_2(input) \quad = \quad RoCoF \quad \leq \quad MAX\_RoCoF$$

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AMPL

Advanced nonlinear optimization:

- Automatic variable substitutions → NN as functions
- Backward automatic derivatives → fast compute; better O(n)

- Modeling environment
- Julia link present

Conclusion

- A novel TSO/DSO coordination approach is proposed to enable the procurement of Ancillary Services (congestion management and voltage control) by the TSO from neighbouring DSOs
- In order to simplify the problem at hand, the proposed approach considers the decoupling of the problem into two sequential stages:
  1) Defining the flexible *active power* at the TSO/DSO interface
  2) Defining the flexible *reactive power* at the TSO/DSO interface
- DA flexibility procurement is solved through a S-MP AC-OPF at the DSO level and a S-MP SC-OPF at the TSO level, which include must-have requisites such as stochasticity or the inclusion of different flexibility sources while still ensuring tractability
- RT DSO and TSO flexibility activation tool addressing:
  - Uncertainty with stochastic MPC (load scaling and constraint penalty factors)
  - N-1 nadir and RoCoF security with NN

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