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TSO-DSO Coordination

Shared Resource Planning

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Motivation

- After the liberalization and unbundling of electricity markets in Europe, electric transmission and distribution systems have been independently managed by Transmission Systems Operators (TSOs) and Distribution System Operators (DSOs):
  - Oversimplification of each other's network models
  - Distribution systems passively operated ("fit-and-forget" approach)

- Electric Power Systems are currently experiencing a profound change:
  - Renewable Energy Sources (RESs)
  - Distributed Energy Resources (DERs)
    - Energy Storage Systems (ESSs)
    - Electric Vehicles (EVs)
    - Active (flexible) consumers
  - Active Distribution Networks (ADNs)

Motivation

- Coordination and active interactions between TSO and DSOs are required to take advantage of the potential benefits that increasing volumes of DERs can bring to the operation of the overall electric power system

- It is expected that the exploitation of these resources will facilitate the integration of RESs at lower costs for consumers by:
  - Reducing the need to procure Ancillary Services (ASs) from conventional generation
  - Reducing investment costs
  - Improving asset utilization

- Technical and regulatory challenges:
  - Computational perspective: management and coordination of a large number of flexible resources connected to Transmission Network (TN) and Distribution Network (DN)
  - Roles and responsibilities of the involved market participants
  - TSOs and DSOs are autonomous control entities with their own rules, policies, and objectives (which may often conflict with each other)

TSO-DSO Coordination Mechanisms

- The TSO-DSO coordination mechanisms proposed in the literature can be broadly classified into:
  - Centralized schemes:
    - TSO, or Independent System Operator (ISO), solves a large-scale problem comprising of TN and DN
  - Decentralized schemes:
    - The large-scale problem is decomposed into smaller subproblems
    - Two main approaches:
      - Hierarchical schemes
      - Distributed schemes

TSO-DSO Coordination Mechanisms

- Hierarchical schemes:
  - Follow a “leader-follower” organization:
    - Each agent (subproblem) performs local decisions that are communicated to the next hierarchical level
    - The SmartNet project proposed a set of five coordination mechanisms widely adopted in the field
  - Distributed schemes:
    - Agents (subproblems) involved in the optimization procedure must reach a consensus regarding common (coupling) variables, e.g., power flows and voltage values at the TN-DN interface nodes

- The advantages of decentralized schemes have made them very popular among researchers in the field, with centralized coordination schemes rarely being used

TSO-DSO Coordination Mechanism
ATTEST Approach

- The ATTEST project proposed a new coordination mechanism:
  - Draws some characteristics from the coordination mechanisms proposed by SmartNet
  - Local markets exist for resources connected to the DN
  - Active and Reactive Power bids are decoupled, and communicated to the TSO via the DSO
  - Procedure:
    1. DERs communicate their bids to their respective DSOs
    2. DSOs compute the **active power flexibility band** they can provide at the TN-DN interface, considering the available DERs, and communicate them to the TSO
    3. TSO computes the **active power profile required** at the TN-DN interface, and communicates it to the DSOs
    4. DSOs compute the **reactive power flexibility band** they can provide at the TN-DN interface, considering the active power profile requested by TSO, and communicate them to the TSO
    5. TSO determines the **reactive power profile** at the TN-DN interface and communicates it to the DSOs
    6. DSOs dispatch the DERs

Role of ESSs in Future Power Systems

- For high levels of renewable energy and consumer participation in power system operation, the balancing task becomes more complicated:
  - Effectively dealing with the uncertainty derived from these types of resources requires more flexibility
- Energy storage increases the flexibility of power systems and therefore their ability to deal with uncertainty is recognized as a valuable means to provide:
  - Additional system security, reliability and capacity to respond to changes that are difficult to accurately forecast
- The increasing uncertainty associated with network operation creates new opportunities for ESS integration at different levels of the electric power systems:
  - Although ESS technology is maturing and continuously reducing in cost, these still require a relatively high initial investment cost
  - Due to unbundling regulation, it is likely that many of these ESSs will be deployed by private investors

Role of ESSs in Future Power Systems

- ESS planning tools:
  - Most of the published work is mainly focused on the optimal investment in ESSs either from an independent investor, DSO, or TSO perspective
  - Only recently the models adopted for ESS planning have started to consider complex topics:
    - Energy capacity degradation
    - Full AC model of the power flow equations
    - Uncertainty associated with the operation of the network (market prices, operational forecasts)
  - Little to no research has been published on the joint-planning of ESSs or planning of ESSs in the presence of TSO-DSO coordination schemes

Proposed Tool
Shared Energy Storage Planning Tool

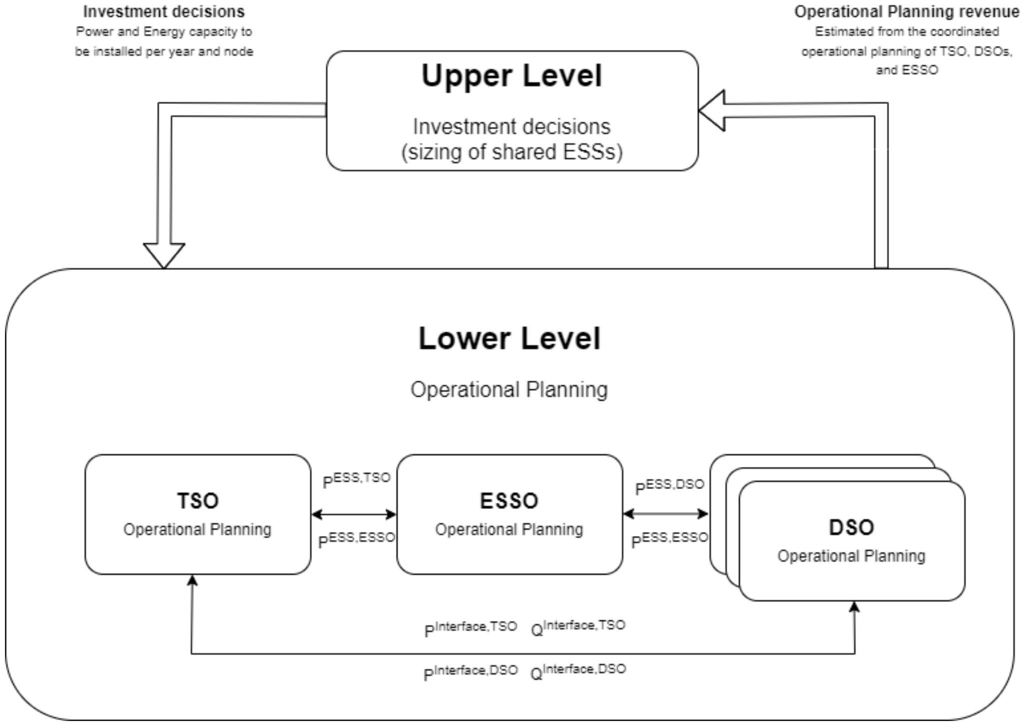
- Shared Energy Storage System Planning:
  - Investment performed by a third-party, private investor (Energy Storage System Owner, ESSO)
  - The shared ESSs can be simultaneously used by TSO and DSOs for the operation of their networks
  - It is considered that the ESSs can be installed at the transmission-distribution interface (with ADNs participating in the coordination scheme)
  - ESSO participates in Energy and Secondary Reserve markets
  - Battery capacity degradation considered in the planning procedure (calendric and cycle aging)

- Stochastic bi-level planning tool:
  - Upper-level (planning): Investment decisions (sizing of the ESS units to be installed)
  - Lower-level: Operational planning (simulation of TSO-DSO coordination, considering market and operation scenarios)

- Decomposition techniques used at the planning and operational planning stages:
  - Tractability
  - Data privacy preservation

Proposed Tool
Proposed Framework

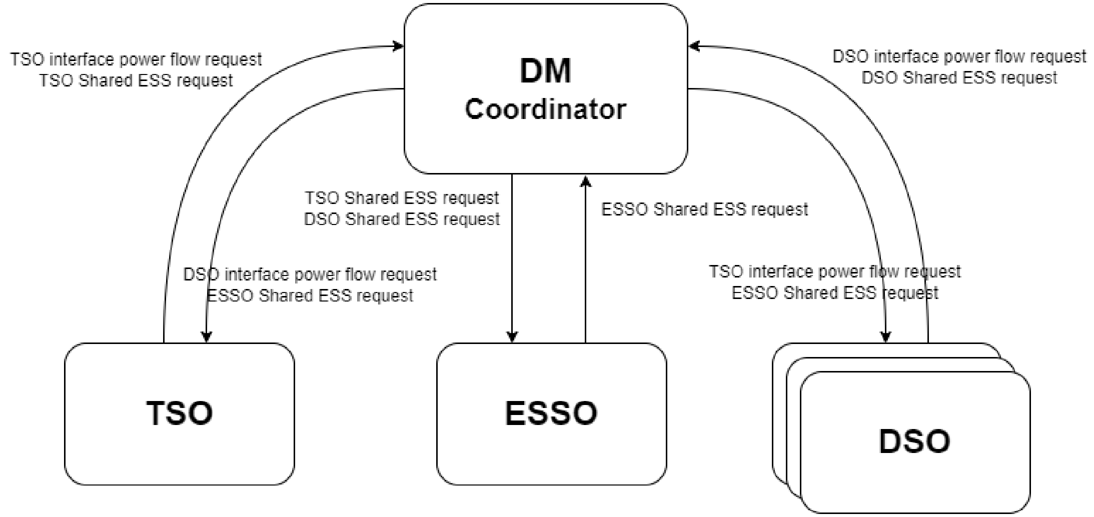
- Upper-level (investment decisions):
  - Power and Energy capacity to be installed per year, and node, subject to budget, energy capacity (related to space occupied at the substation), and power/energy ratio constraints
  - The value of the upper-level's objective function is the lower bound of the overall problem
- Lower-level (coordinated operational planning):
  - Estimation of the operational revenue
  - TSO, DSOs, and ESSO coordinate their operation to determine the shared ESS power profile, and active and reactive power flows at the TN-DN interface
  - The value of the lower-level's objective function is the upper bound of the overall problem



Convergence is obtained when the lower and upper bounds of the overall problem converge to an admissible tolerance

Proposed Tool
TSO-DSO Coordination Mechanism in the Presence of Shared ESSs

- To mathematically formulate the TSO-DSO coordination mechanism in the presence of shared ESSs, the proposed TSO-DSO coordination mechanism was upgraded and implemented using the Alternating Direction Method of Multipliers (ADMM):
  - The lower-level is decomposed by the several actors that participate in the coordination mechanism (TSO, DSOs, ESSO)
  - A consensus must be reached regarding the coupling variables of the operational planning problem (active and reactive power flow at the TN-DN interface, and power profiles of the shared ESSs)

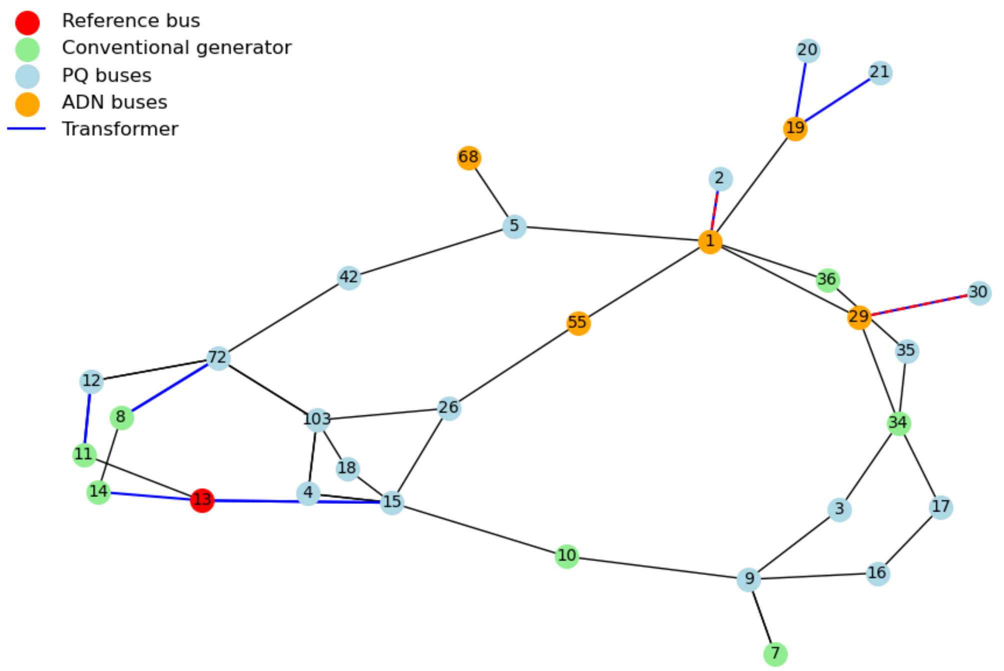


- This coordination scheme is relative complex, when compared to other coordination schemes proposed in the literature (e.g., hierarchical schemes), but it brings several benefits:
  - Considers the existence of shared resources that can be simultaneously used by TSO and DSOs, and that can provide additional ASs
  - Reflects the full potential of the flexibility available at the DN-level (impact of voltage magnitude at the interface node, intertemporal characteristics of DERs)

Case Study

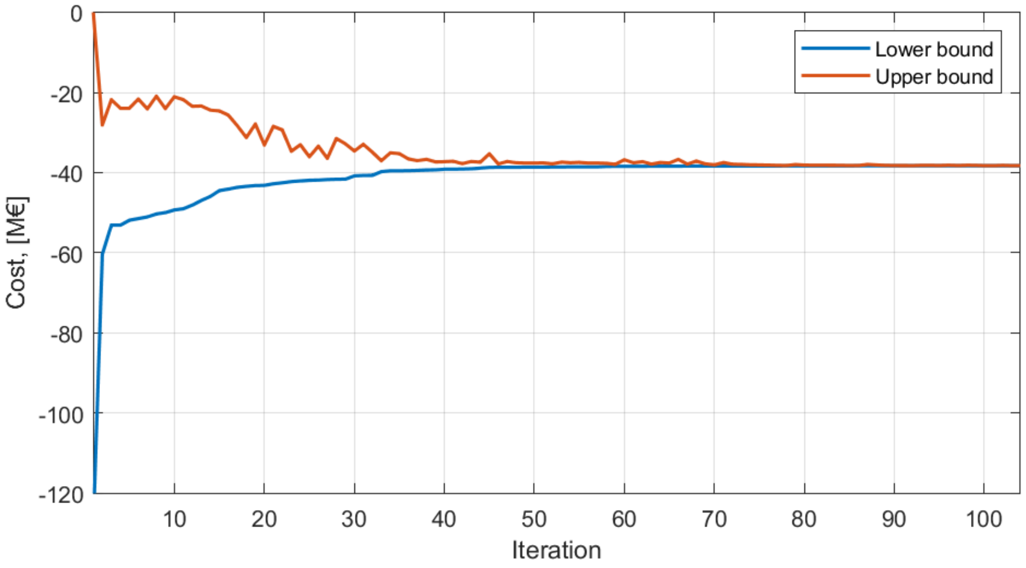
- Croatian network – Koprivnica region:
  - Network data provided by HOPS and HEP ODS
  - A total of 5 ADNs were considered in the
- Assumptions:
  - Budget: 1 M€
  - 4 representative years, 1 representative day/year
  - Load growth 1.25%, flexibility growth 5.00%
  - Power-to-energy capacity ratio between 0.10 and 4.00 (Li-Ion batteries), calendar life 20 years, max 2.50 MVAh
  - Costs (NREL projections for utility-scale battery ESSs):

Capacity Cost	2020	2030	2040	2050
Power, [€/MVA]	69000.00	39600.00	34800.00	29800.00
Energy, [€/MVAh]	27600.00	158400.00	139200.00	119200.00



Case Study
Results

- Convergence: 104 iterations, 53,948.63s (~15h), to a relative tolerance of 0.10%
- ESSO's estimated profit (NPV): 38.24 M€



- Investment plan (per year):

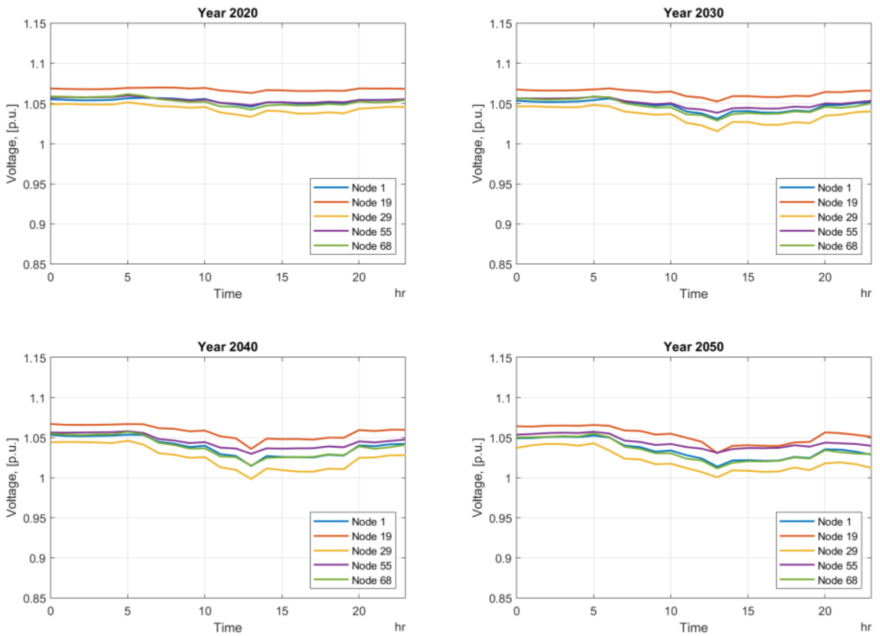
Node ID	Capacity	2020	2030	2040	2050
55	Power, [MVA]	0.000	0.015	2.964	0.000
	Energy, [MVAh]	0.000	0.004	2.404	0.000
68	Power, [MVA]	0.000	0.015	3.343	0.000
	Energy, [MVAh]	0.000	0.004	2.496	0.000
29	Power, [MVA]	0.000	0.000	0.588	0.000
	Energy, [MVAh]	0.000	0.000	0.708	0.000
1	Power, [MVA]	0.000	0.000	2.090	0.000
	Energy, [MVAh]	0.000	0.000	1.759	0.000
19	Power, [MVA]	0.000	0.001	3.348	0.000
	Energy, [MVAh]	0.000	0.000	2.500	0.000

ESSO tends to invest towards the end of the planning period (lower investment costs, networks operating closer to their technical limits)

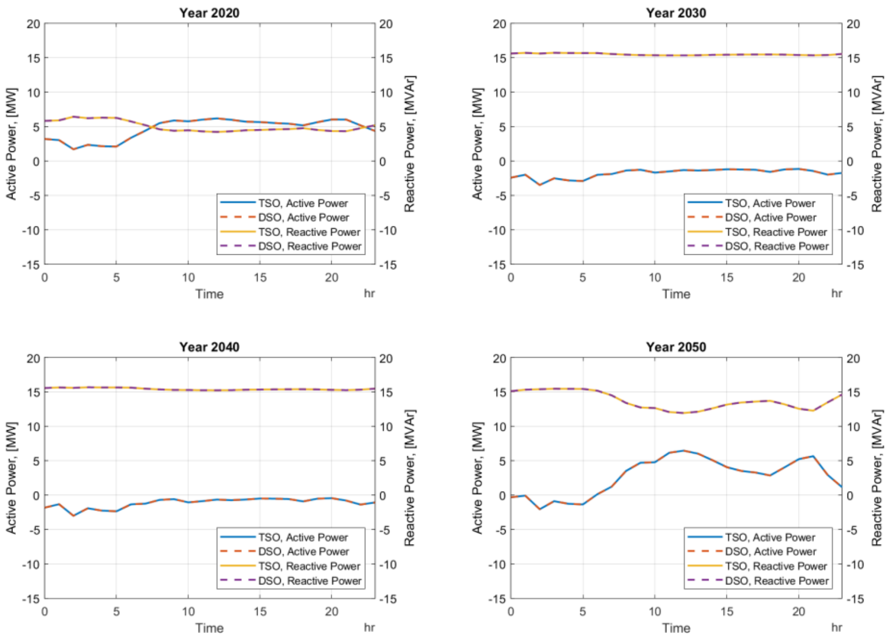
Case Study
Results

- Transmission-Distribution Interface

Voltage



Active and Reactive Power Flows. ADN Node 68



- Voltage magnitude fluctuations at the TN-DN interface increase significantly over the planning period (but staying between the limits), specially until 2040
- Between 2040 and 2050, the voltage magnitude fluctuations remain approximately constant

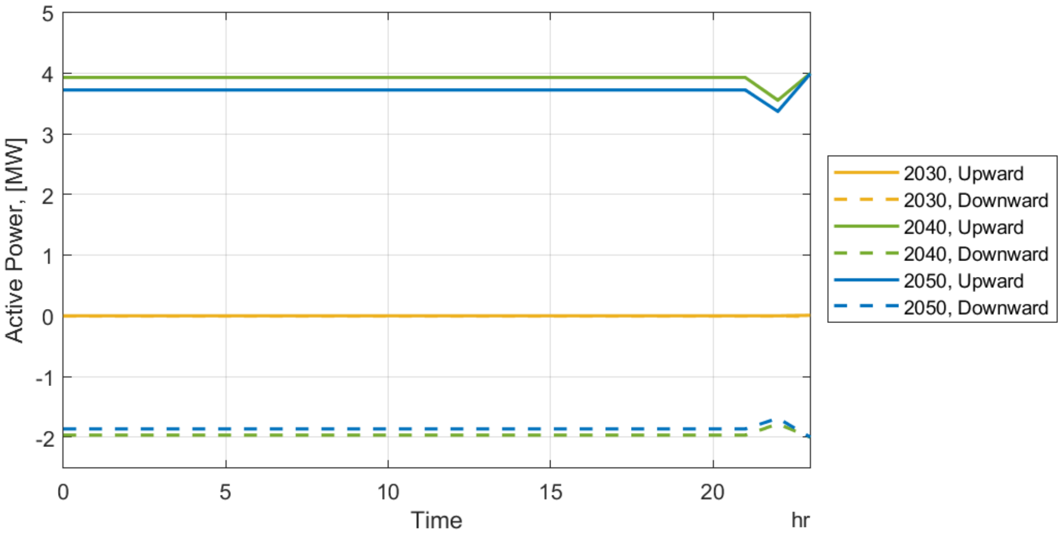
- TSO and DSOs reach a consensus regarding the active and reactive power flows
- Reactive power flow changes significantly. Reactive power support (voltage control), requested by TSO

Case Study
Results

- Shared ESSs

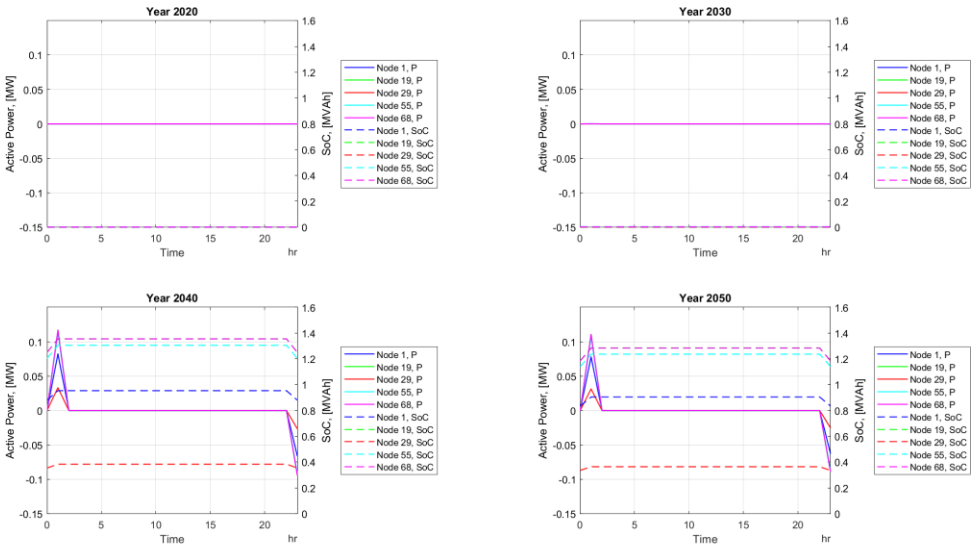
MIBEL: upward secondary reserve is double of the downward secondary reserve

Secondary Reserve



- Secondary reserve in 2030 is very small, due to the small size of the shared ESSs installed
- Highest value in 2040, when most of the shared ESS capacity is installed
- In 2050, the secondary reserve bands decrease, due to energy capacity degradation

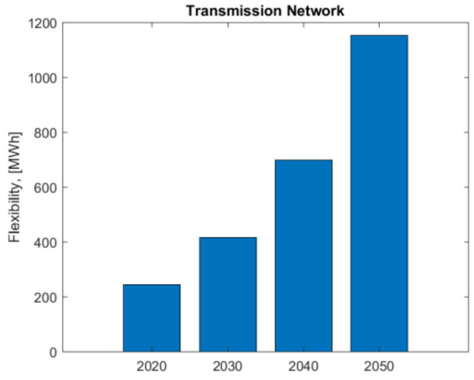
Active power and State-of-Charge

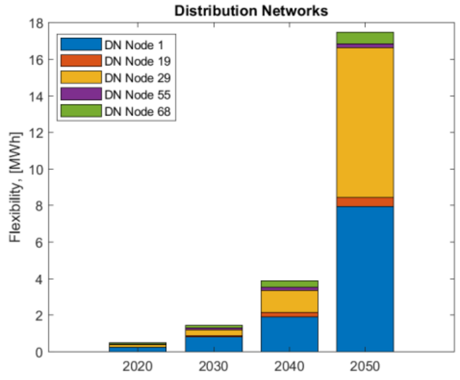


- In 2030, shared ESSs do not participate in the energy market:
  - More profitable to the ESSO to participate in the secondary reserve market;
  - TSO and DSOs recur to other flexibility-providing resources to optimize network operation
- In 2040 and 2050, shared ESSs participate in the energy market

Case Study
Results

- Flexibility usage:

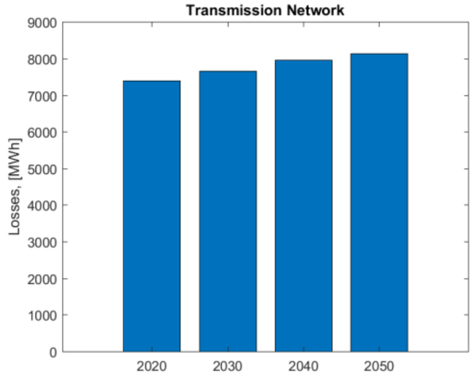


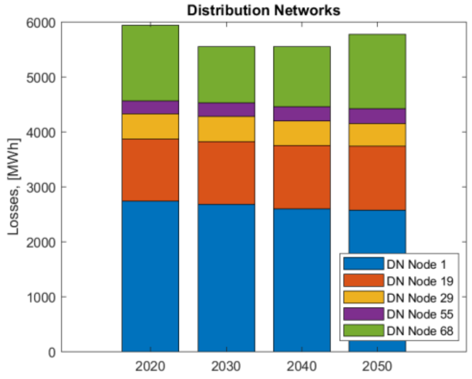


The flexibility required from flexible consumers increases exponentially:

- Much more drastic at the DN-level
- Used not only by DSO for the management of their own network, but also to support the operation of the TN

- Losses:





The growth of flexibility-providing resources brings benefits also in terms of network losses (although it is not a direct objective of the coordination scheme):

- At the TN-level, losses increase at a slower rate than the adopted load growth
- At the DN-level, network losses decrease between 2020 and 2040, and increase in 2050 (to a lower value than in 2020)

Conclusions

- We proposed a novel TSO-DSO Shared Resource Planning Tool, under a new TSO-DSO coordination mechanism proposed by the ATTEST project, that was extended to consider shared resources
- TSO and DSOs are able to coordinate their operation in the presence of shared resources, by sharing a relatively small volume of information, and this coordinated operation brings several benefits to the operation of the overall power system
- The proposed coordination mechanism can provide additional ASs, not considered by other TSO-DSO coordination mechanisms, such as frequency regulation reserve
- Future work:
  - Study additional services that can be provided by shared ESSs
  - Study the application of convex OPF models to the operational planning subproblems of each operator, with the objective of determining the eventual benefits in the convergence characteristic of the overall problem

Thank You

Questions

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