Learning-based Coordination of Transmission and Distribution Operations

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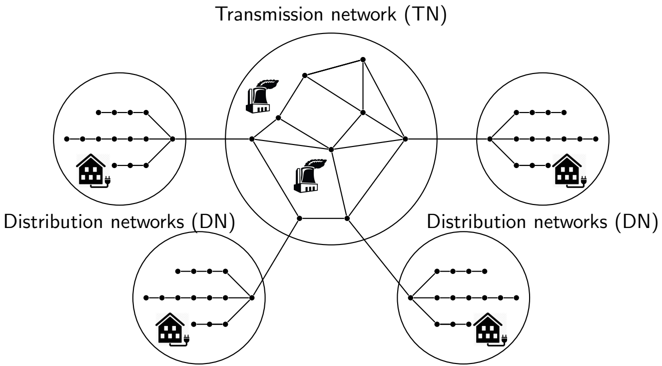
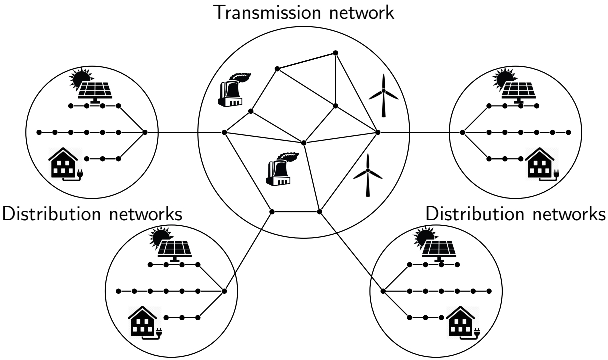
Transmission-Distribution in the past



- DN only included inflexible consumers
- DN's consumption was easily predicted
- TN operation was determined by replacing DN with fix loads
- Low computational burden, no information exchange

Transmission-Distribution in the future



- DN includes flexible consumers and DERs
- DN's consumption is sensitive to the electricity price
- How should TN be operated in this scenario?

Methods for TSO-DSO coordination

- Exact methods
  - Centralized
  - Decomposition
  - Decentralized
- Approximate methods
  - Single-bus
  - Price-agnostic
  - Price-aware

Methods for TSO-DSO coordination

- Exact methods
  - Centralized
    - Full representation of transmission and distribution networks
    - Full access to all distribution networks information
    - Very high computational time
  - Decomposition
  - Decentralized
- Approximate methods
  - Single-bus
  - Price-agnostic
  - Price-aware

Methods for TSO-DSO coordination

- Exact methods
    - Centralized
    - Decomposition
        - Few complicating constraints/variables allow for decomposition
        - Full access to all distribution networks information
        - Significant time reductions
    - Decentralized
- Approximate methods
    - Single-bus
    - Price-agnostic
    - Price-aware

Methods for TSO-DSO coordination

- Exact methods
  - Centralized
  - Decomposition
  - Decentralized
    - Iterative methods with limited information exchange
    - It relies on robust communication infrastructure
    - Significant time reductions
- Approximate methods
  - Single-bus
  - Price-agnostic
  - Price-aware

Methods for TSO-DSO coordination

- Exact methods
    - Centralized
    - Decomposition
    - Decentralized
- Approximate methods
    - Single-bus
        - All topology parameters of DNs are ignored
        - Very low computational time
        - Good results only for uncongested DNs
    - Price-agnostic
    - Price-aware

Methods for TSO-DSO coordination

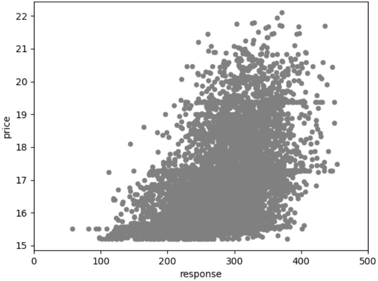
- Exact methods
  - Centralized
  - Decomposition
  - Decentralized
- Approximate methods
  - Single-bus
  - Price-agnostic
    - It assumes that the response of DNs is independent of price
    - It only requires access to historical data at main substation
    - Good results only for passive DNs
  - Price-aware

Methods for TSO-DSO coordination

- Exact methods
  - Centralized
  - Decomposition
  - Decentralized
- Approximate methods
  - Single-bus
  - Price-agnostic
  - Price-aware
    - It accounts for network congestion and price impact
    - It only requires access to historical data at main substation
    - Response of DNs dependent on contextual information

Contextual price-aware approach (PAW)

1) For each DN, we have access to price-response historical data



2) For a given context, we select the closest price-response pairs
3) We approximate the data using a step-wise non-increasing function
4) We operate the TN using the step-wise functions

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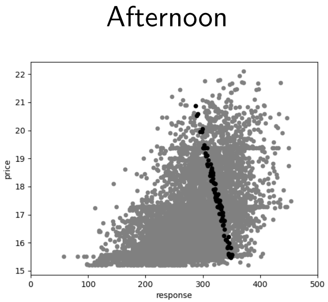

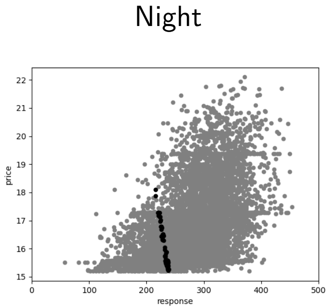

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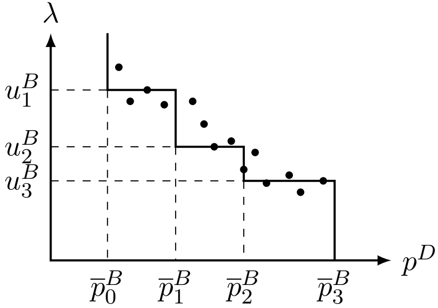

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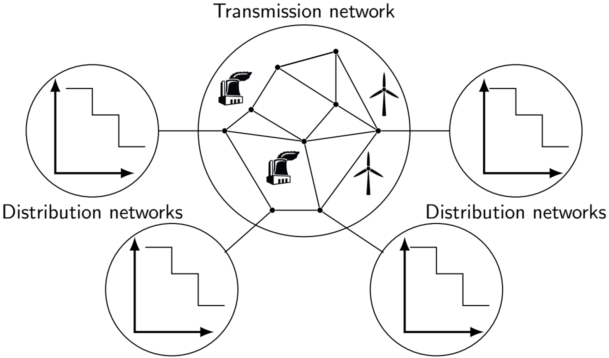


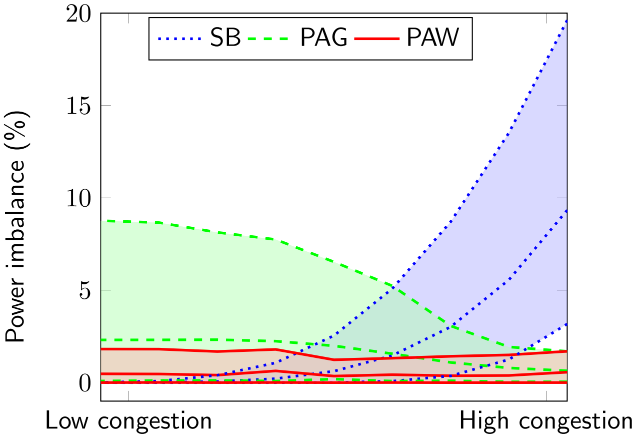
Evaluation procedure

1) Solve the operation of the TN using the following approximations:
   - Single-bus (SB)
   - Price-agnostic (PAG)
   - Price-aware (PAW)
2) Determine the electricity prices at substations
3) Compute the optimal operation of DNs for those prices
4) Quantify the power imbalance between expected and actual response
5) Measure the social welfare loss with respect to the exact solution

Case study

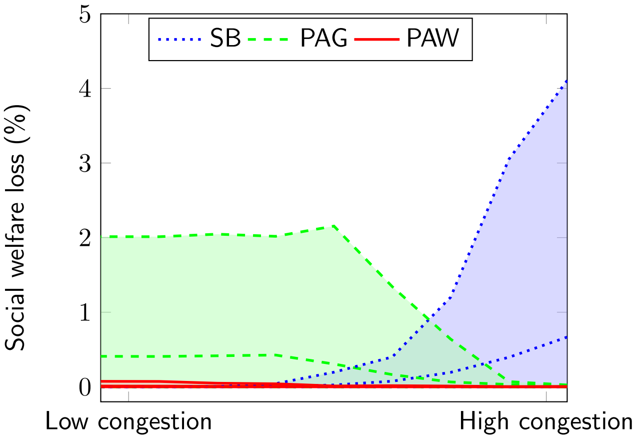
- 1 TN with 118 buses and 186 lines
- 91 DN with 32 buses and 32 lines
- DN include flexible consumers and solar power units
- End-customers react linearly to price
- DN parameters are varied to simulate different congestion levels
- Demand and solar forecast used as contextual information
- 8760 hours for training and 100 hours for testing

Results



- SB works for low congestion since network can be disregarded
- PAG works for high congestion since response is independent of price
- PAW works for low and high congestion. Average imbalance $< 0.7\%$

Results



- Maximum loss for SB and PAG are 2% and 4%, respectively
- Maximum loss for PAW is 0.1%

Conclusions

- Exact methods for TSO-DSO coordination rely on access to private information and/or robust communication infrastructures
- We propose a learning-based approach that
  - only requires measurement data at substations
  - does not depend on communication infrastructure
  - uses a step-wise function to model the response of DN
  - can be easily implemented in current market procedures
  - accounts for contextual information
- If compared with other approximations, the proposed approach
  - reduces the power imbalances ($< 0.7\%$)
  - reduces the social welfare loss ($< 0.1\%$)

Thanks!! Questions??

Optimization and Analytics for Sustainable energY Systems

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J.M. Morales, S. Pineda, and Y. Dvorkin, "*Learning the price response of active distribution networks for TSO-DSO coordinations*", under review