KTH ROYAL INSTITUTE OF TECHNOLOGY

System balancing at nearly 100% renewable generation

PhD project

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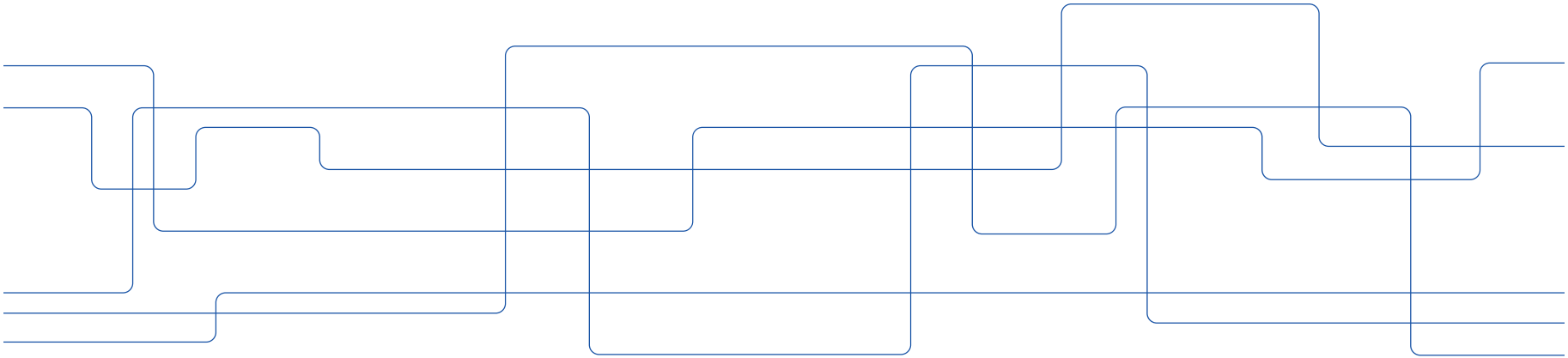
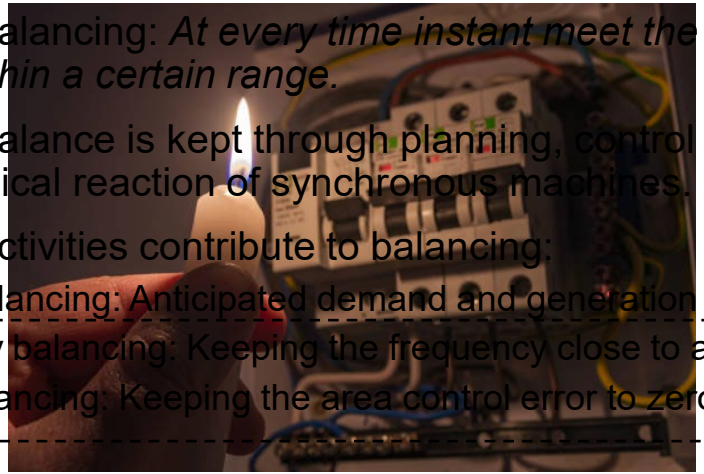


Outline

- Power system balancing - challenges with high share of wind power
- Scenario ”Electrification renewables 2045”
- Including balancing in long-term simulations
- How to efficiently handle balancing at a high share of wind power?
- Current and future work

Power system balancing

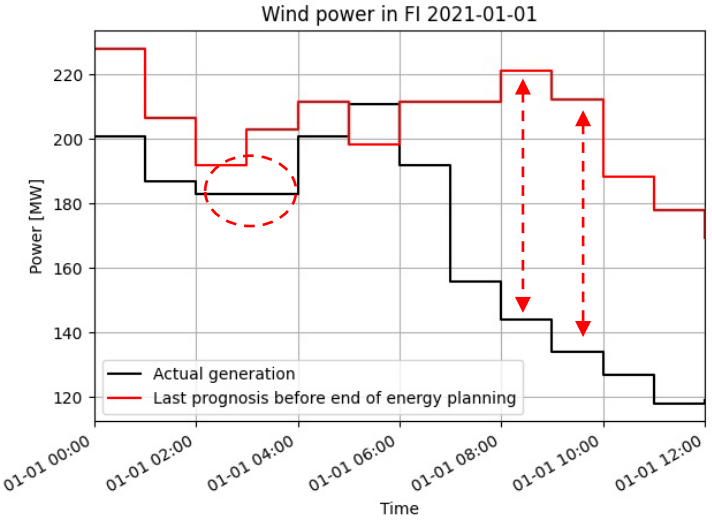
- In power systems, there IS always a balance between supplied and consumed power.
  - During a blackout?
- Continuous balancing: *At every time instant meet the electricity demand while keeping the frequency within a certain range.*
- Continuous balance is kept through planning, control systems, manual actions, and the inherent physical reaction of synchronous machines.
- Three main activities contribute to balancing:
  - Energy balancing: Anticipated demand and generation is matched in markets.
  - Frequency balancing: Keeping the frequency close to a nominal level in a synchronous system.
  - Power balancing: Keeping the area control error to zero in a balancing area.



Balancing services

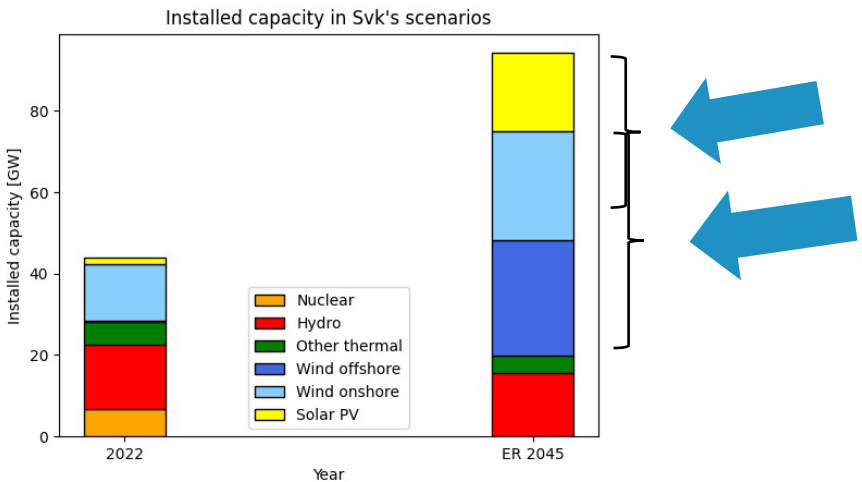
Balancing challenges with high share of wind

- Finnish wind power data to illustrate the challenges.
- Wind power brings more uncertainty to the energy balancing.
- Wind power brings more variability within the planning periods.
- Wind power does not provide inertia.



Electrification renewables 2045

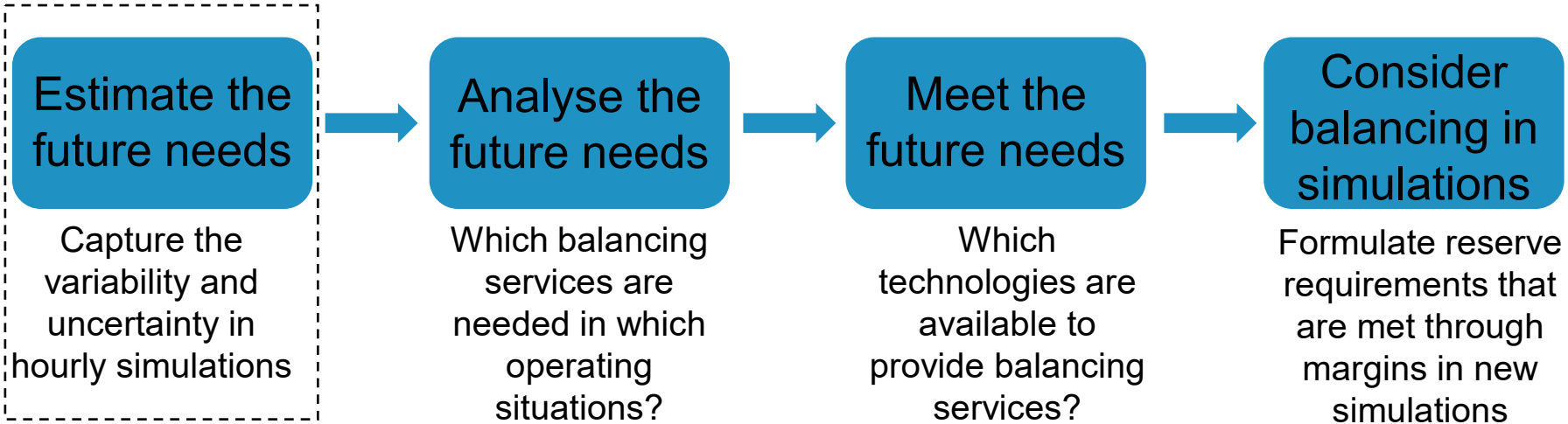
- Project is based on Svk's scenario of a nearly 100% renewable Nordic system year 2045.
- Power system dispatch simulated with hourly resolution for 35 years of weather data in Svk's long-term market analysis [1].
- About 59% of installed capacity in Sweden is wind power!
- Demand about twice as high in Sweden – large potential for flexibility
- Balancing will be challenging!



[1] Svenska kraftnät, Långsiktig marknadsanalys 2021, 2021, https://www.svk.se/siteassets/om-oss/rapporter/2021/langsiktig-marknadsanalys-2021.pdf

Including balancing in long-term simulations

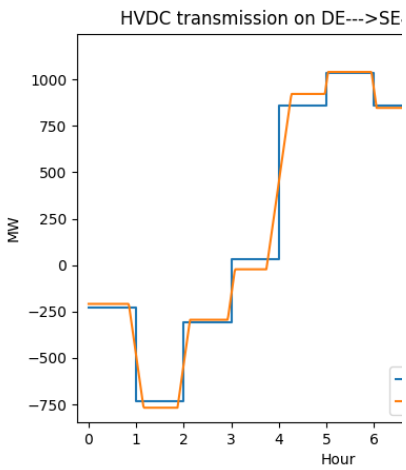
- Balancing at a high share of wind power is clearly an important challenge – should be considered in future scenario studies.
- Currently, only the hourly energy balancing is simulated in Svk's studies.
- Could be considered by keeping margins in resources based on simulated operating conditions. This is performed in North American studies like [2].
- How can we perform such studies in the Nordic countries? Need to know which margins to keep where.

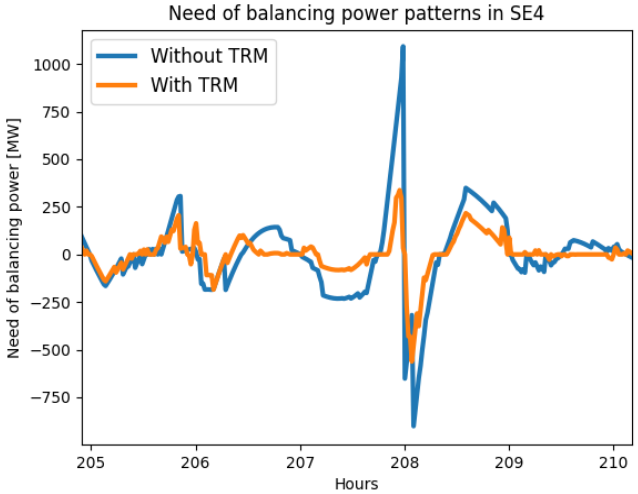


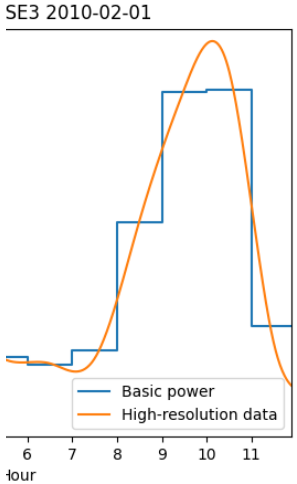
[2] Brinkman, G. et al. (2021). *The North American Renewable Integration Study: A US Perspective—Executive Summary*. www.nrel.gov/publications.

Estimating the need of balancing power

- A model to estimate the need of balancing power was presented in [3].
- Main idea: Interpolation methods to extend hourly simulations to higher resolution.
  - Simplified wind power modelling – method to better capture uncertainty and variability is being developed.
- Every minute: Area need of balancing power = (Consumption + Export) – (Production + Import)







[3] Nordström, H., Söder, L., & Eriksson, R. (2022). Estimating the Future Need of Balancing Power Based on Long-Term Power System Market Simulations. *Proceedings of 11th Bulk Power Systems Dynamics and Control Symposium (IREP 2022)*.

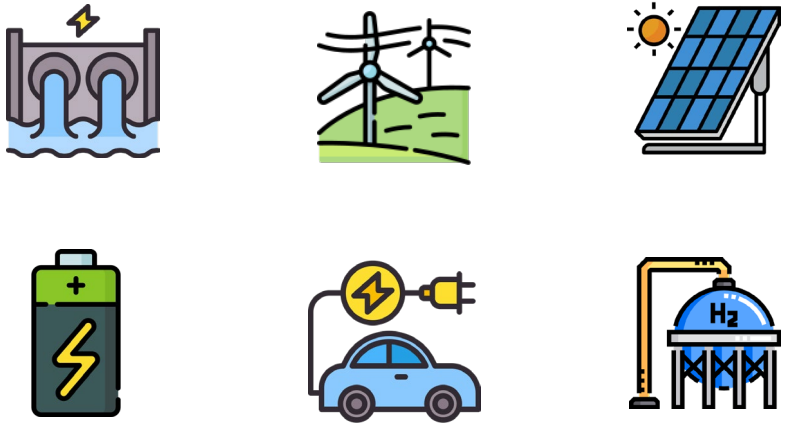
Keeping balance at high share of wind power

- How to handle the continuous balance in systems with high share of wind power?
- Strategies and outlooks vary between systems and countries. Work on international review.
- Depends on:
  - Future needs
    - More wind and solar will increase the challenge.
  - Balancing principles
    - 15 minutes trading period means more granular energy balancing.
    - Dynamic methods to determine balancing service needs instead of static methods.
  - Available technologies
    - How much could the demand side contribute? EVs, electrolysers, batteries and demand flexibility.
  - Market design/Regulation for balancing services
    - Power balancing will be handled through the European platforms MARI and PICASSO.

Current/Future work

- Ongoing projects:
  - Review of current outlooks on how different systems will handle continuous balancing at high wind power penetration. International collaboration article within IEA Wind TCP: Task 25.
  - Improved modeling of high-resolution wind power in future scenarios.
  - Towards dynamic dimensioning of FRR in the Nordic power system. Collaboration with A. Khodadadi.
- Future work:
  - Developing methods to set reserve requirements in a nearly 100% renewable Nordic system.
  - Investigate which technologies could provide with cost-efficient balancing services.
  - Estimate future costs of balancing services.
  - Include reserve procurement in future long-term scenario simulations.

Thank you!



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