15.2.2024

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Measures to address stability issues in the Finnish power system

ESIG webinar 15.2.2024

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Contents

- Introduction to Fingrid and the Finnish electricity system transition
- Stability phenomena in the Finnish grid and ways used to address them
  - Frequency stability
  - Voltage stability
  - Rotor angle stability
  - Resonance stability
  - Converter driven stability
- Conclusions


Customers as enablers of the transition
Efficiently utilised main grid
Extensive and predictable electricity markets
Operations and competence in transition
FOCAL POINTS OF DEVELOPMENT
We cost-effectively secure reliable electricity for our customers and society, and we shape the clean, market-oriented power system of the future.
TRANSPARENT
FAIR
EFFICIENT
RESPONSIBLE
OUR VISION
The energy system is clean, reliable and creates economic prosperity for Finland. Fingrid is the cornerstone of the energy system.
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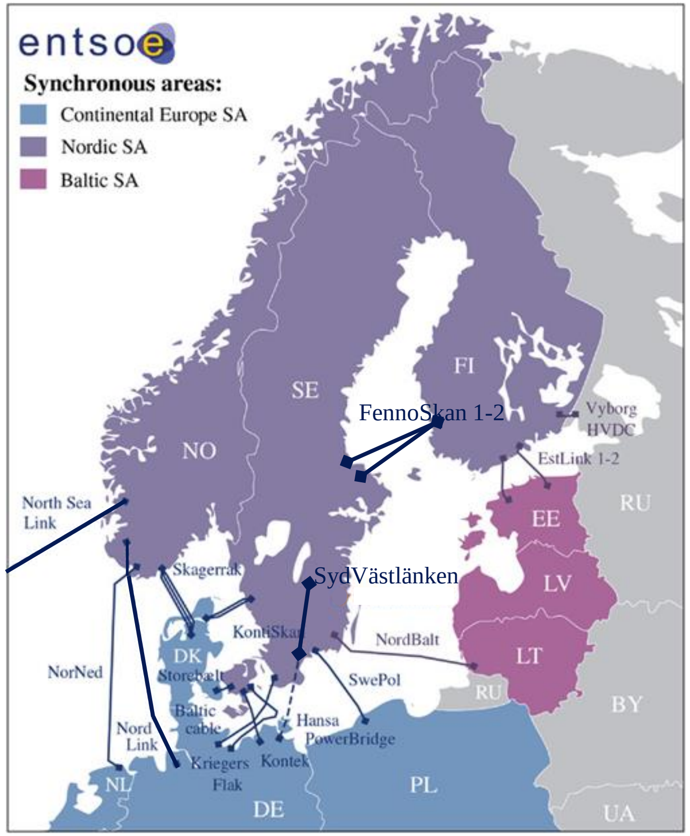
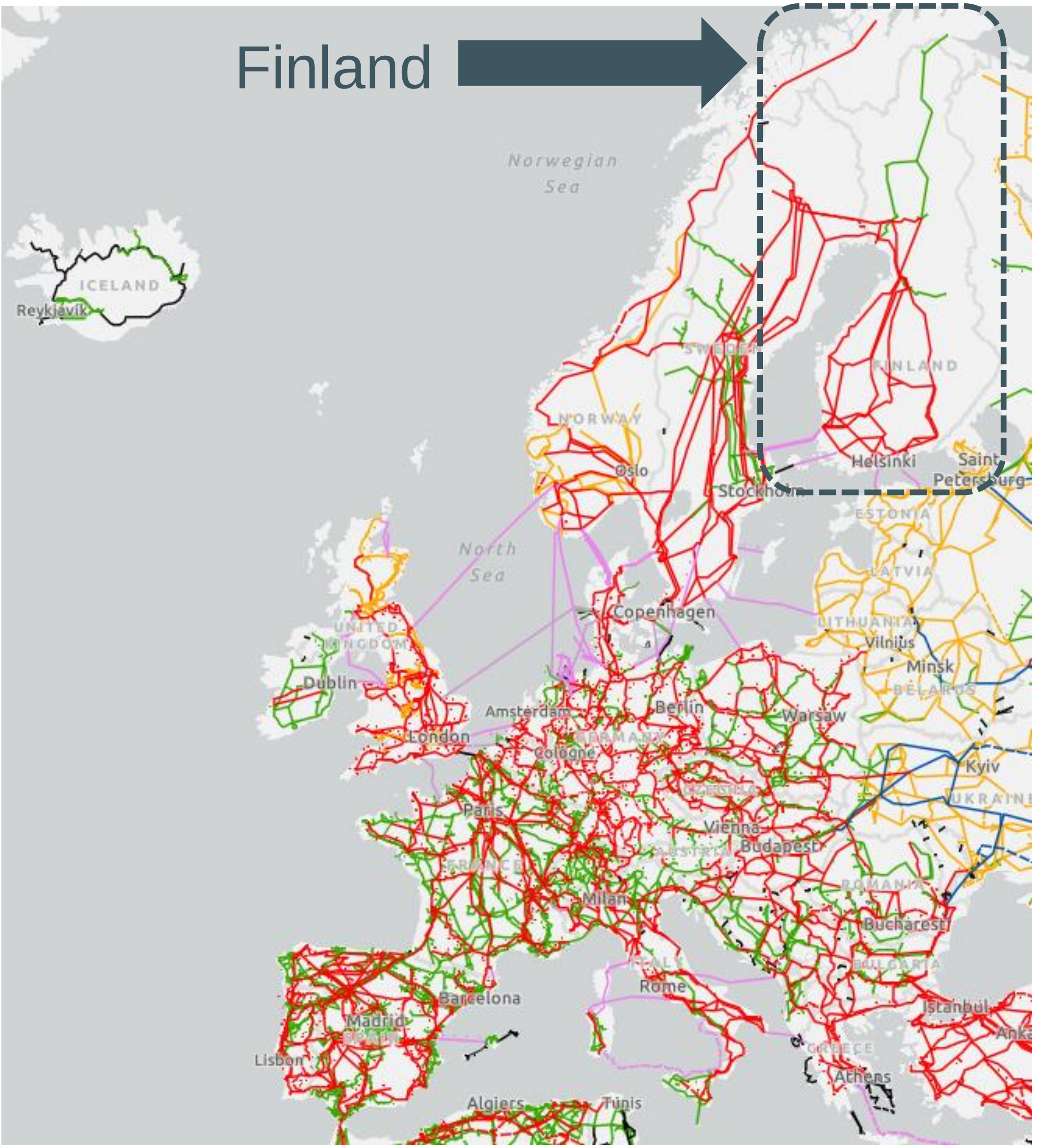
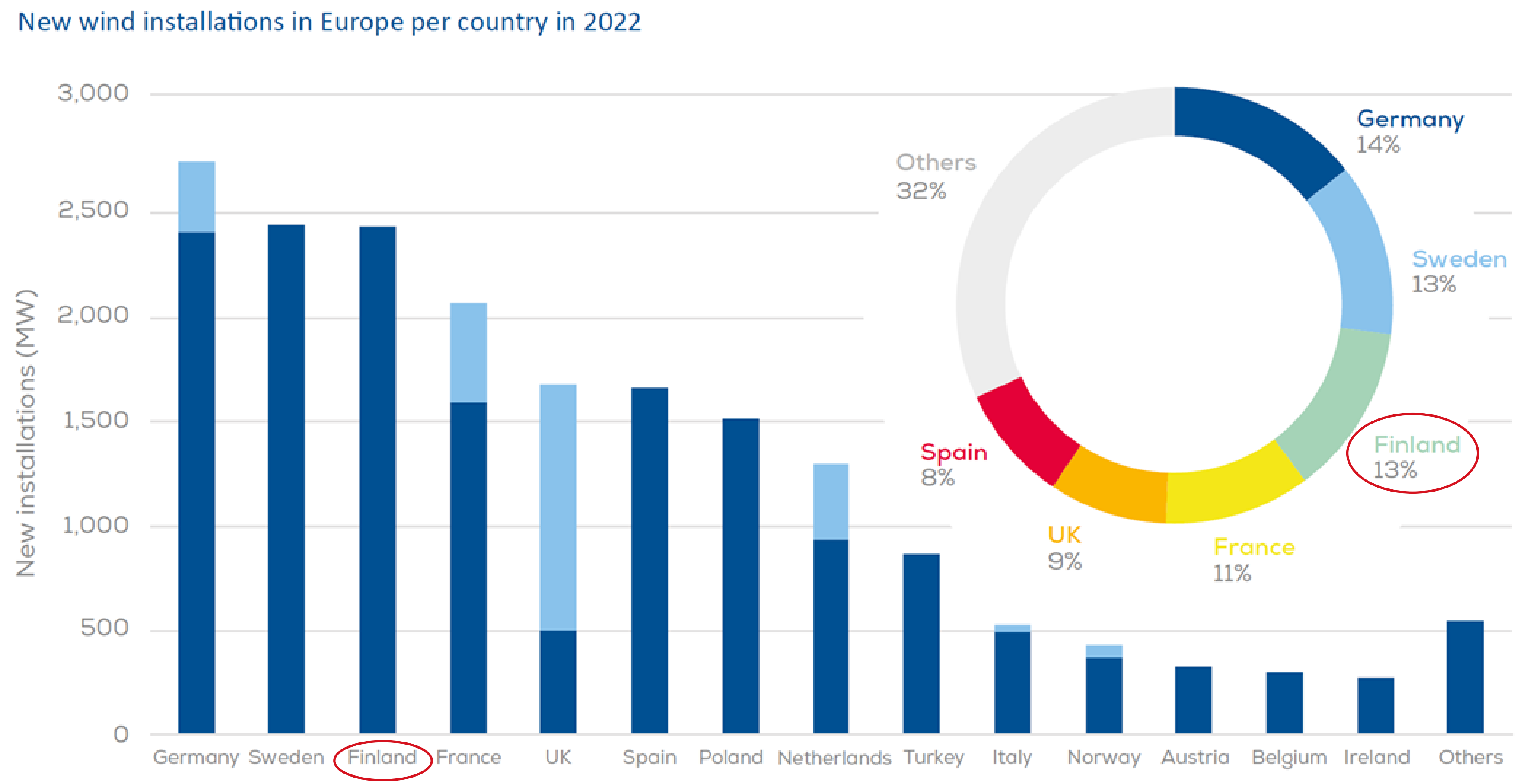
Nordic synchronous area and Finnish transmission system





Source: ENTSO-E

Lots of new wind power production



	Germany	Sweden	Finland	France	UK	Spain	Poland	Netherlands	Turkey	Italy	Norway	Austria	Belgium	Ireland	Others
Onshore	2,403	2,441	2,430	1,590	502	1,659	1,517	933	867	496	372	328	303	280	546
Offshore	342	0	0	480	1,179	0	0	369	0	30	60	0	0	0	0

Source: WindEurope

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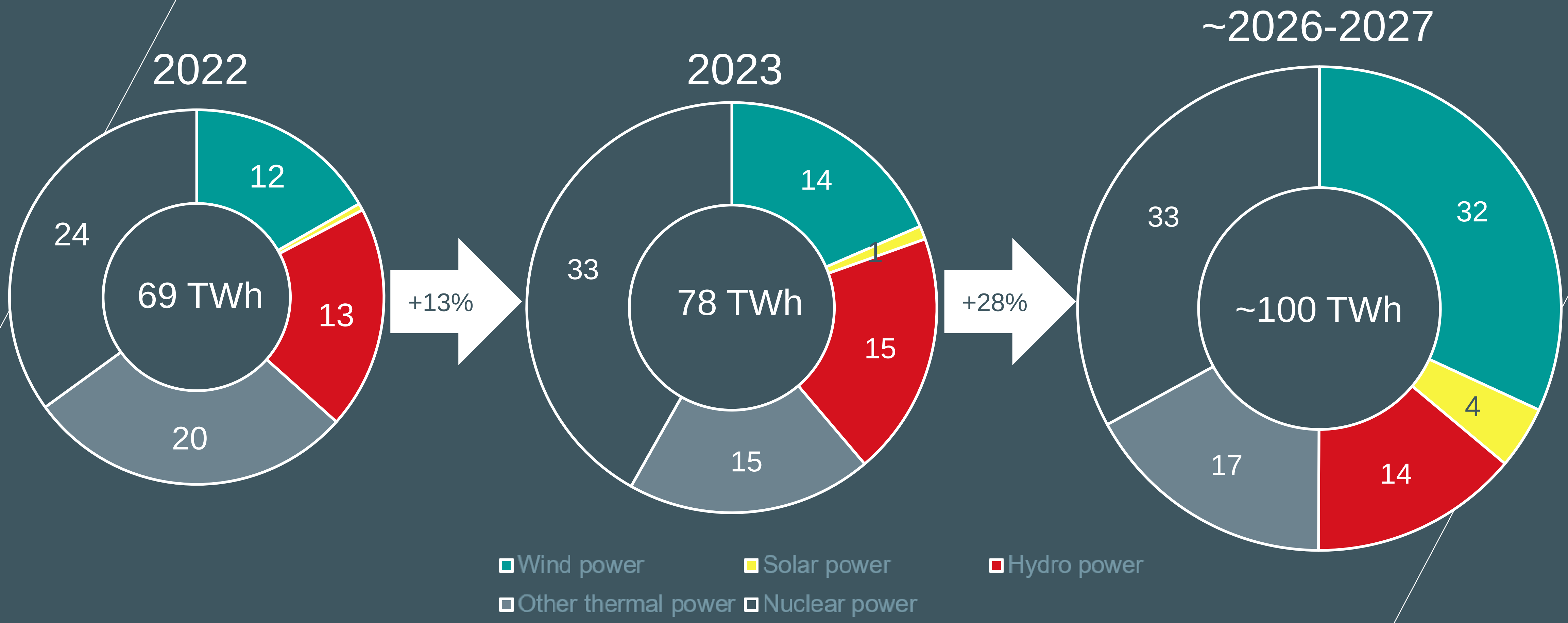
Power generation capacity growth set to continue in Finland



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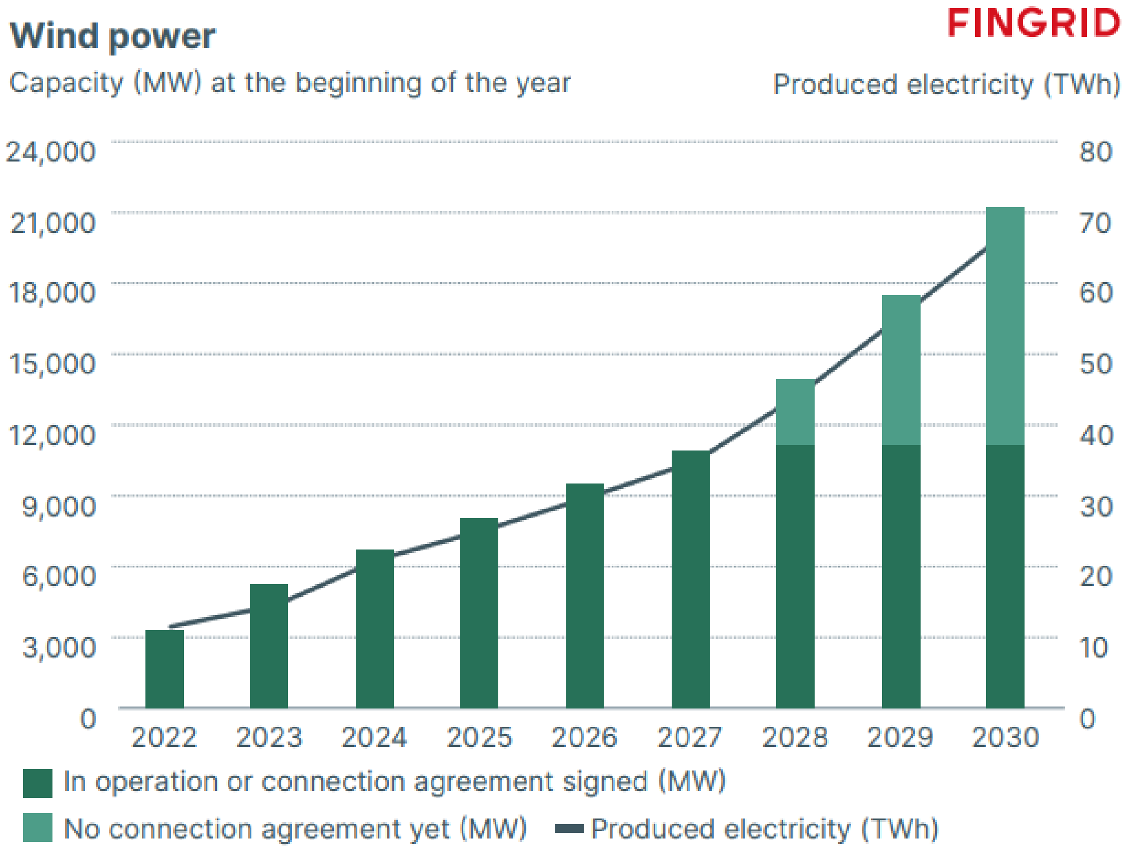
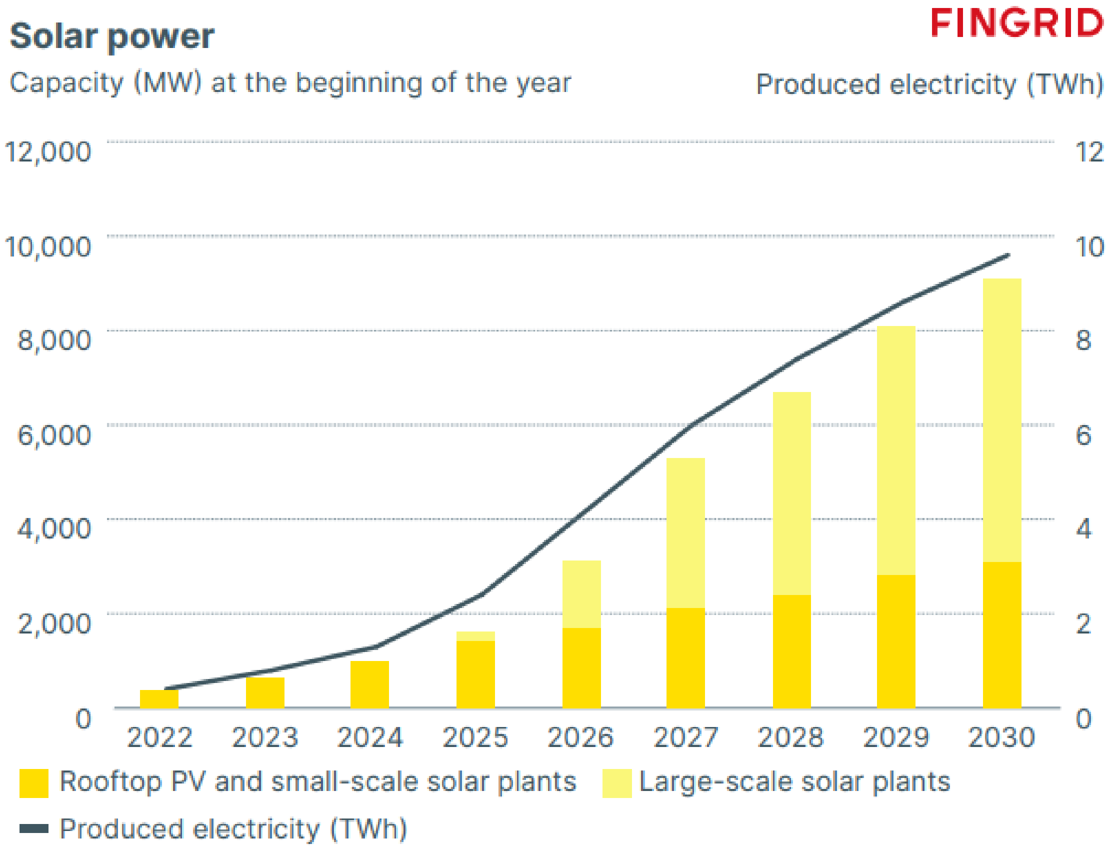
Projected development of wind and solar power





https://www.fingrid.fi/en/news/news/2024/prospects-for-future-electricity-production-and-consumption-updated--fingrid-prepares-for-substantial-growth-during-the-ongoing-decade/

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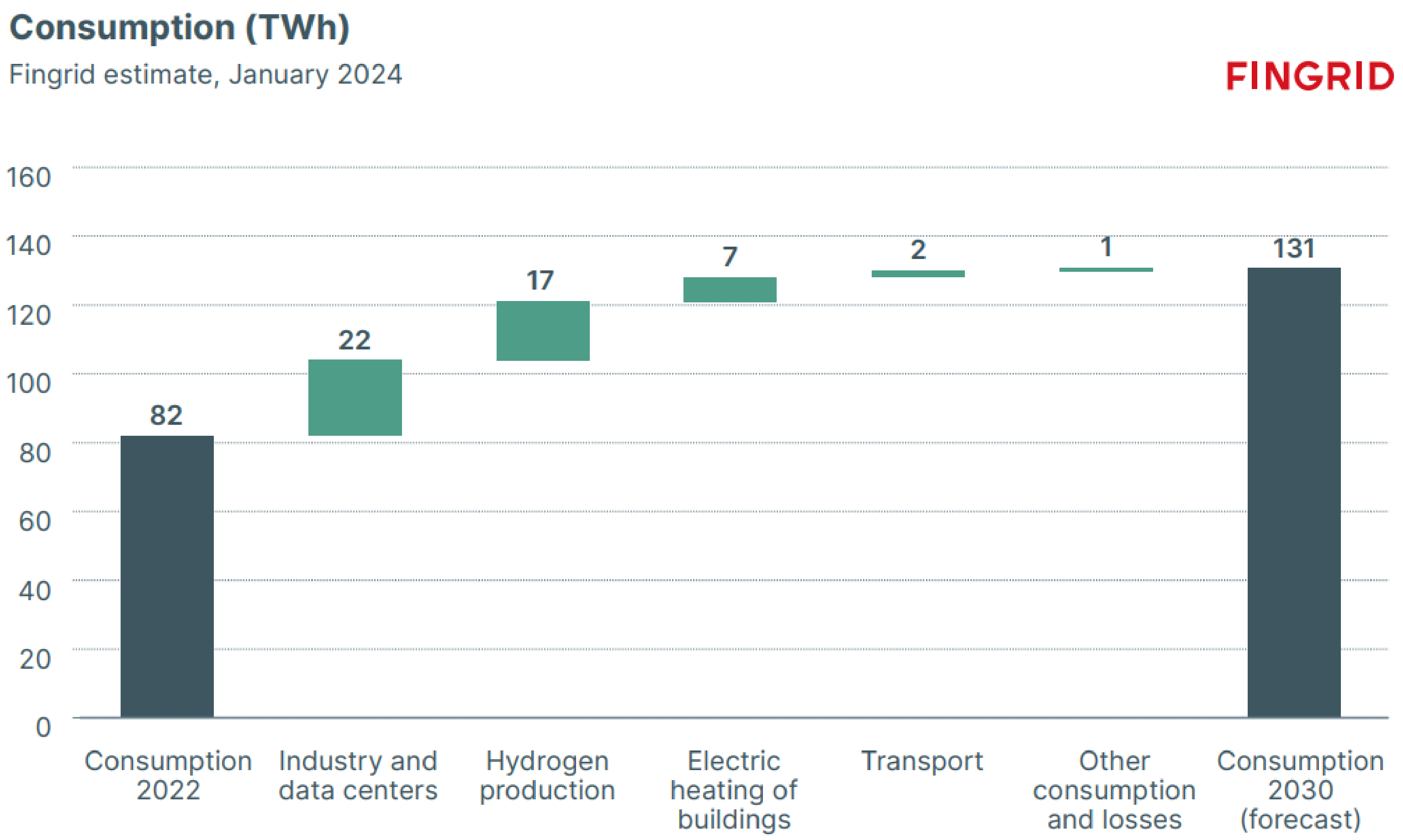
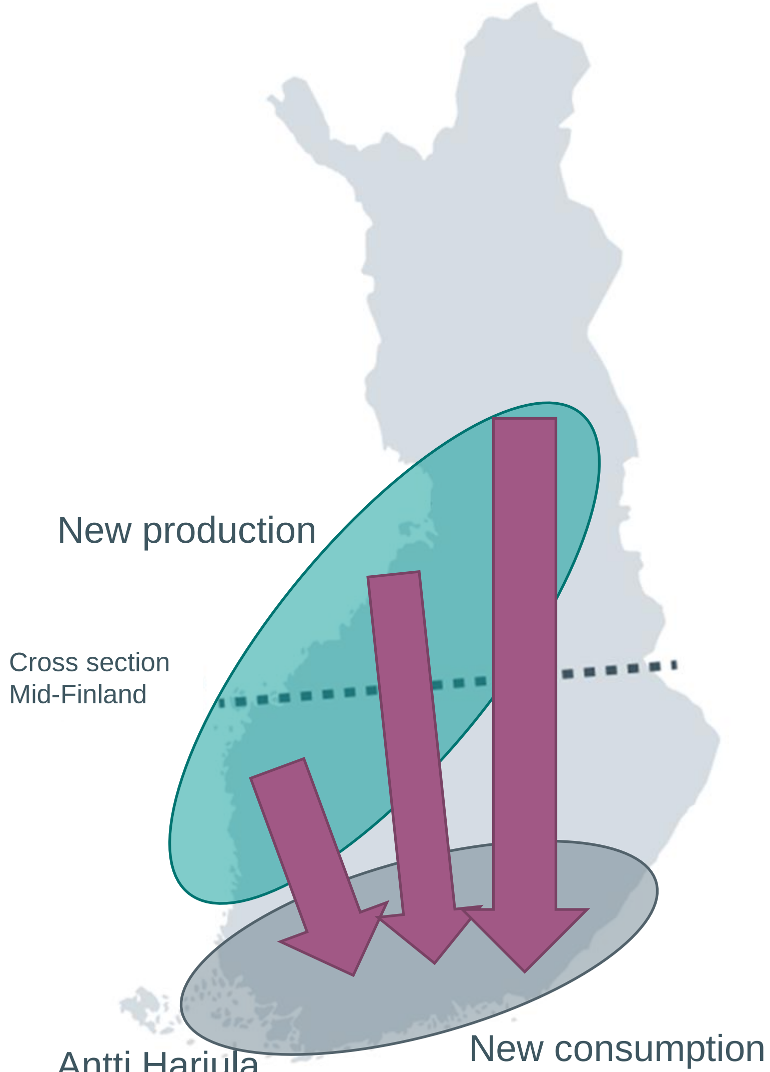
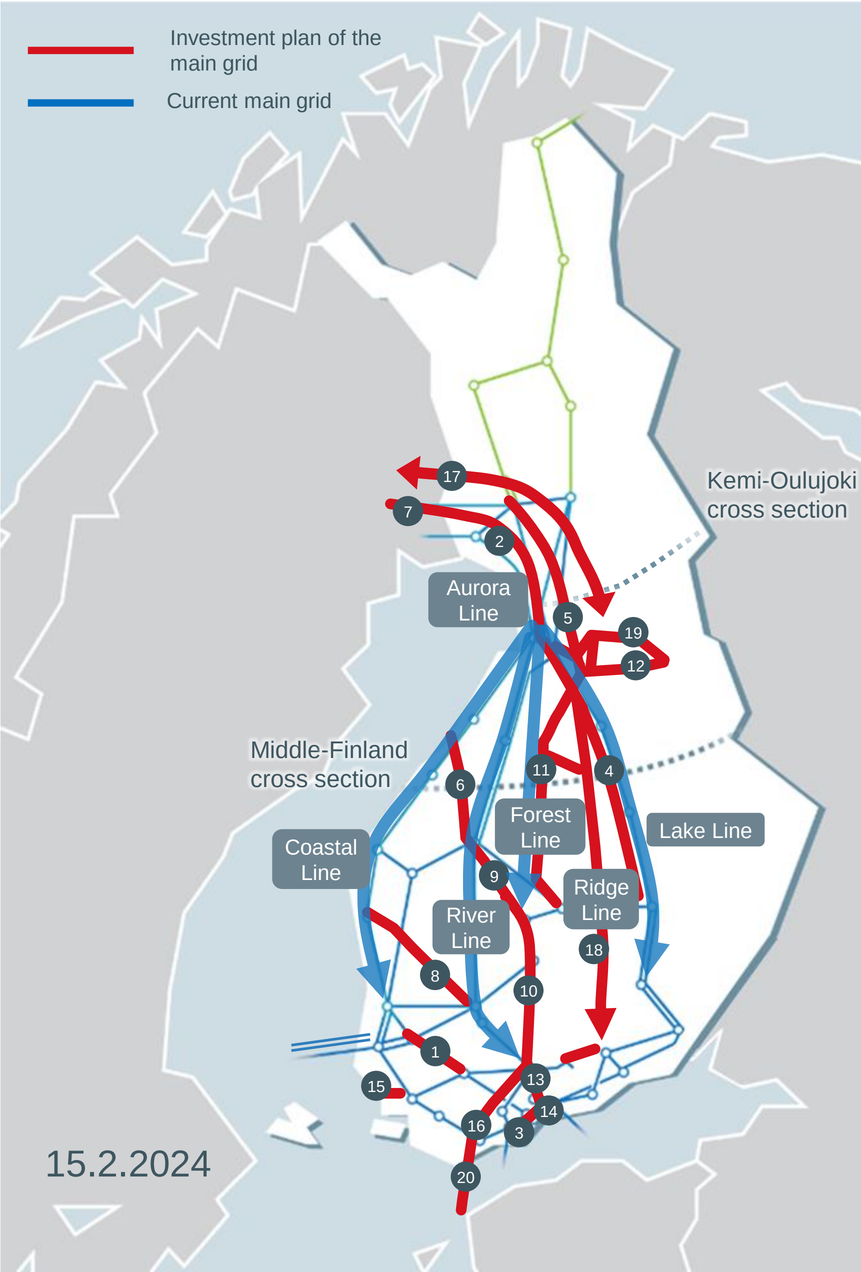
Wind power expected to increase industrial consumption



Growing amount of power to be connected and to be transmitted





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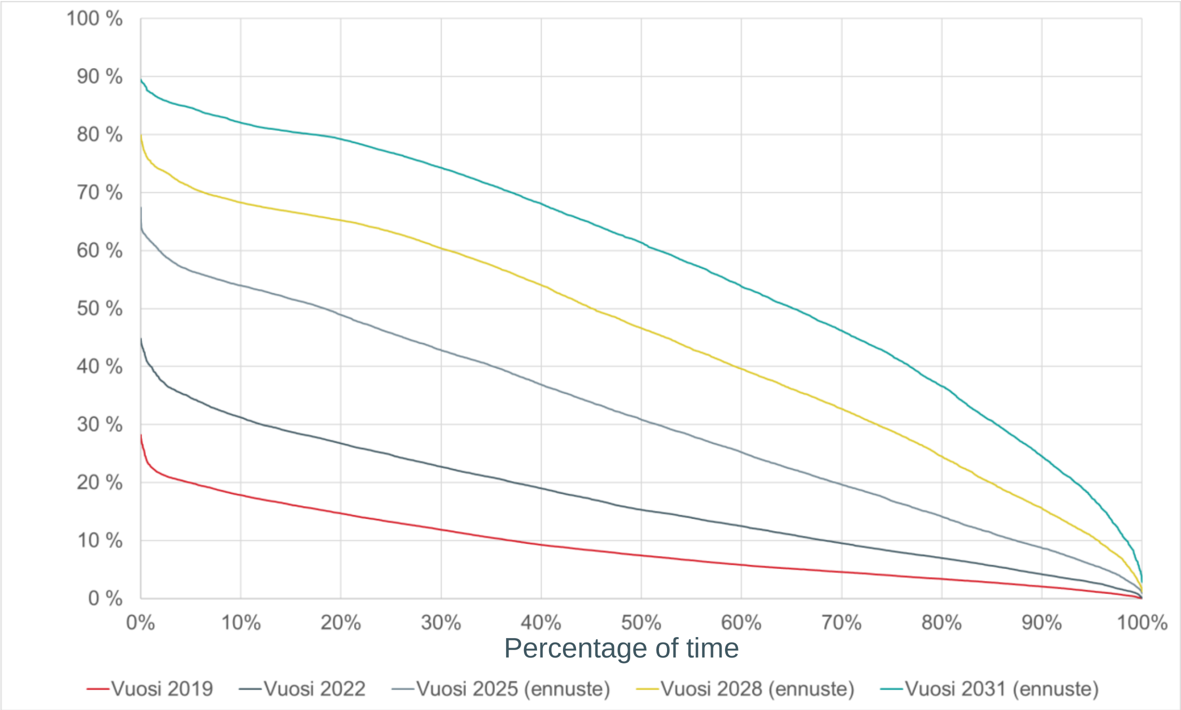
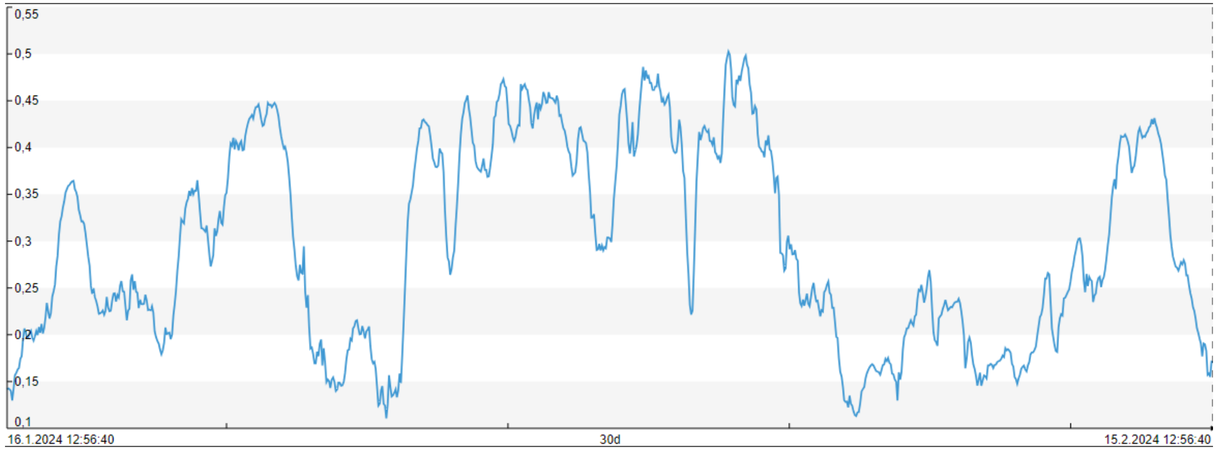
Share and volatility of solar and wind of instantenous generation is increasing rapidly

Projected duration curves of instantaneous share of wind and solar in Finland



Instantaneous share of IBR during last 30 days



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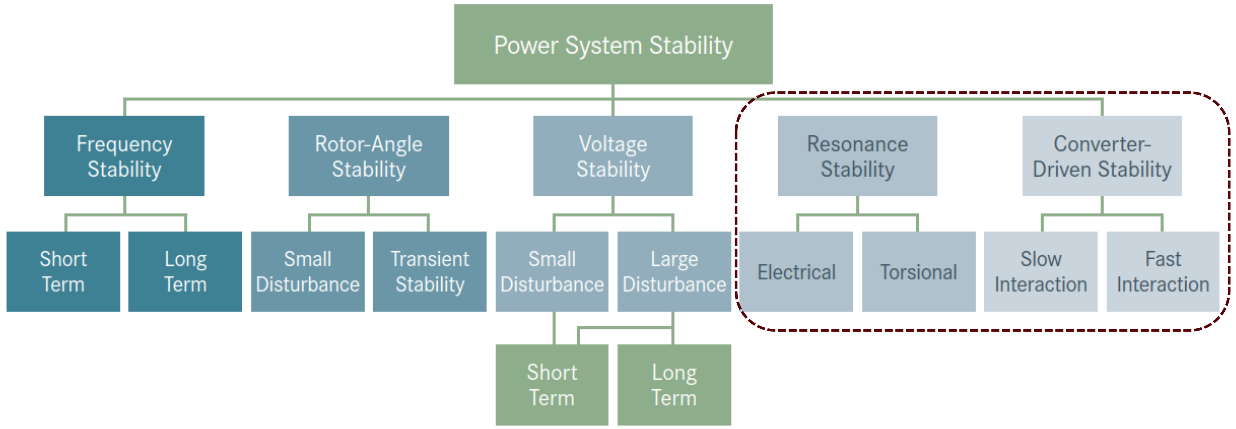
Change in system characteristics - stability



Power system stability phenomena changes with increase in power electronic interfaced equipment.

New level of accuracy in models, and new ways to analyse, mitigate and monitor are needed.

N. Hatziargyriou et al., "Definition and Classification of Power System Stability – Revisited & Extended", in IEEE Transactions on Power Systems, July 2021

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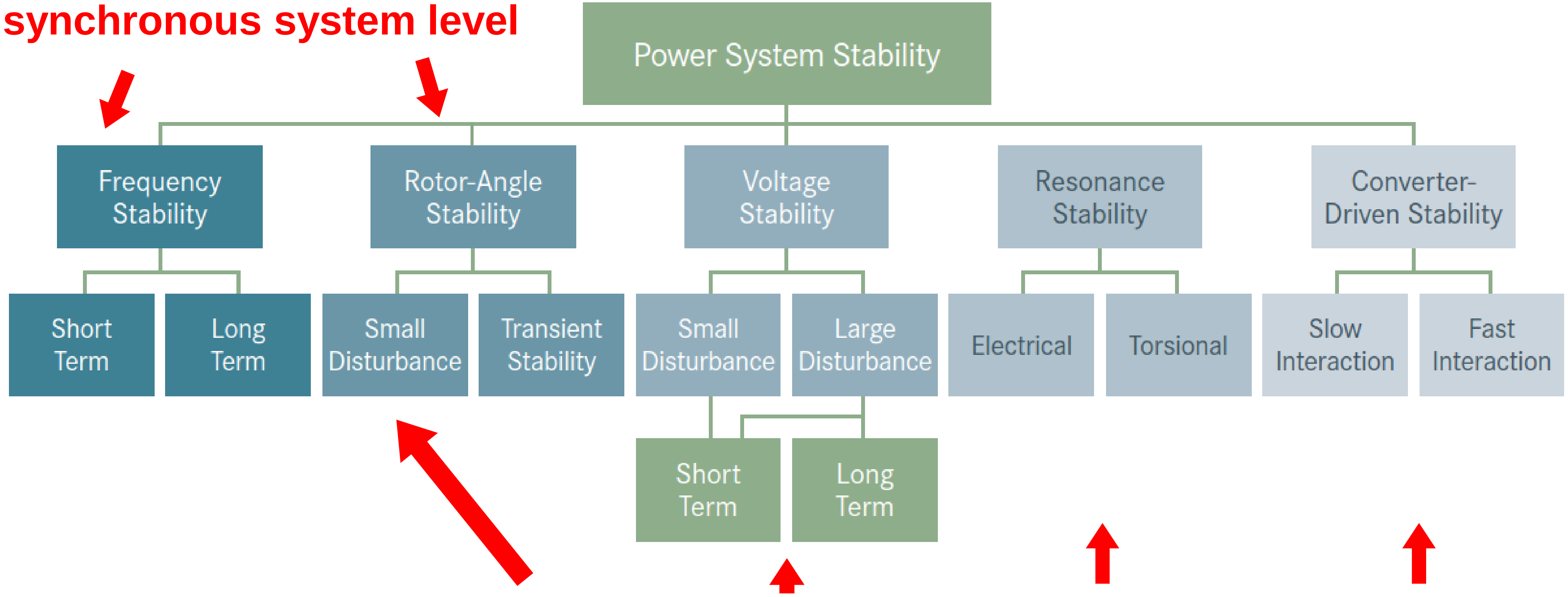
Power system stability phenomena

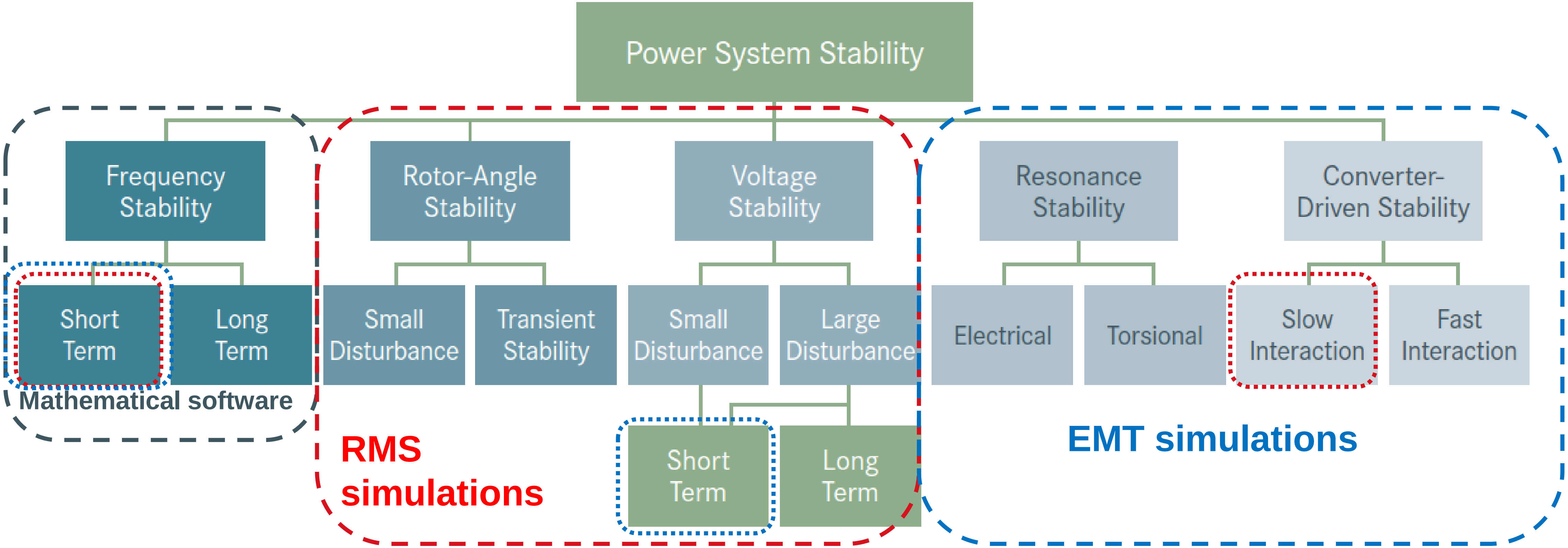
Main technical challenges on synchronous system level



Main technical challenges within the Finnish part of the system

N. Hatziargyriou et al., "Definition and Classification of Power System Stability – Revisited & Extended", in IEEE Transactions on Power Systems, July 2021

Power system stability phenomena analysis and main tools



N. Hatziargyriou et al., "Definition and Classification of Power System Stability – Revisited & Extended", in IEEE Transactions on Power Systems, July 2021

Frequency stability

Frequency stability

- Frequency control through reserve market products
- Fastest product is Fast Frequency Reserve (FFR)
  - FFR is triggered when the frequency crosses the activation threshold. The activation threshold is at 49.5 Hz, 49.6 Hz or 49.7Hz. The full activation time is 0.7–1.3 seconds depending on the activation threshold.
  - The amount of kinetic energy in the Nordic power system determines the required amount of FFR capacity to keep the frequency minimum above 49.0 Hz in case of a loss of the reference incident. This amount is dynamic over the hours of a day and over seasons, due to the constant change of kinetic energy.

- In studies it is checked that local Rate of Change of frequency is kept well bellow 2 Hz/s

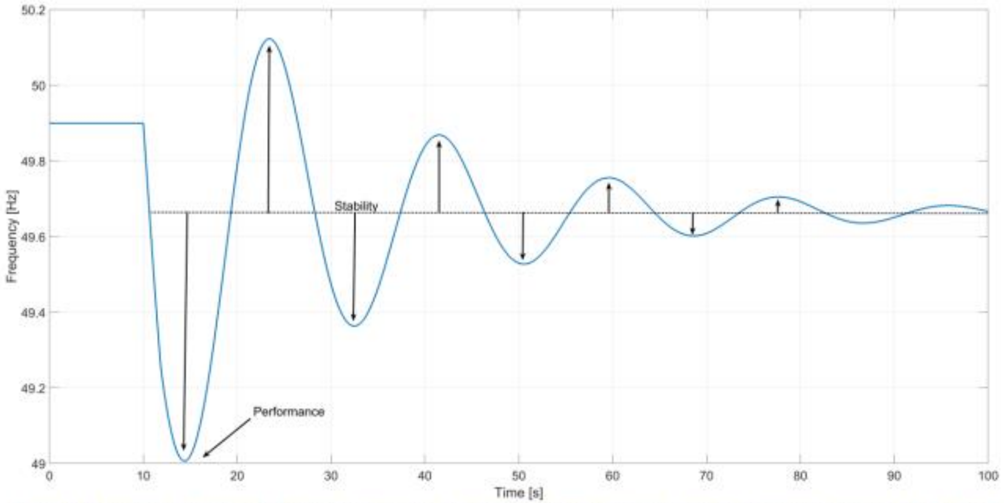
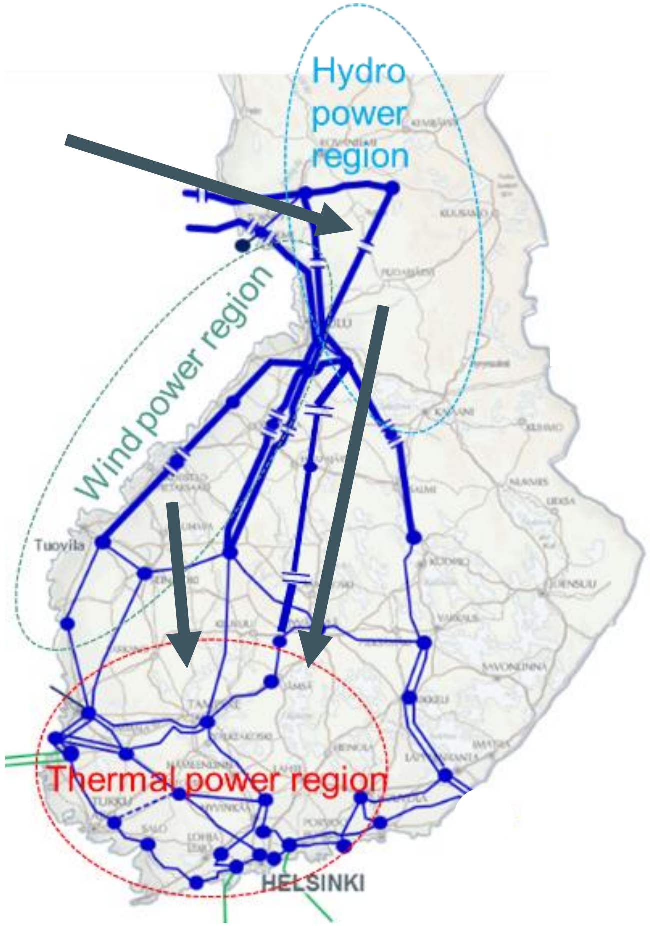


Figure 3: Frequency disturbance illustrating the aspect of performance as the ability to limit the frequency deviation for the initial swing and the stability as the ability to dampen the following frequency oscillations.

Source: ENTSO-E Overview of Frequency Control in the Nordic Power System 15.3.2022

Voltage stability

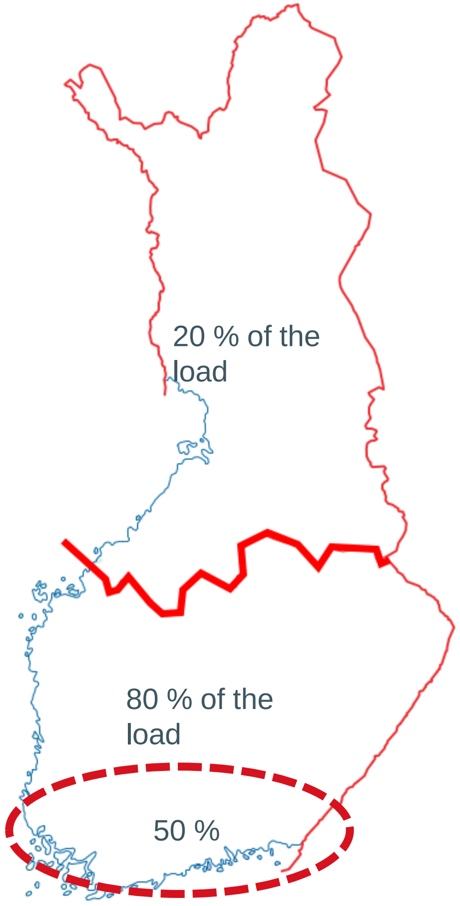
Voltage stability – Large and small signal



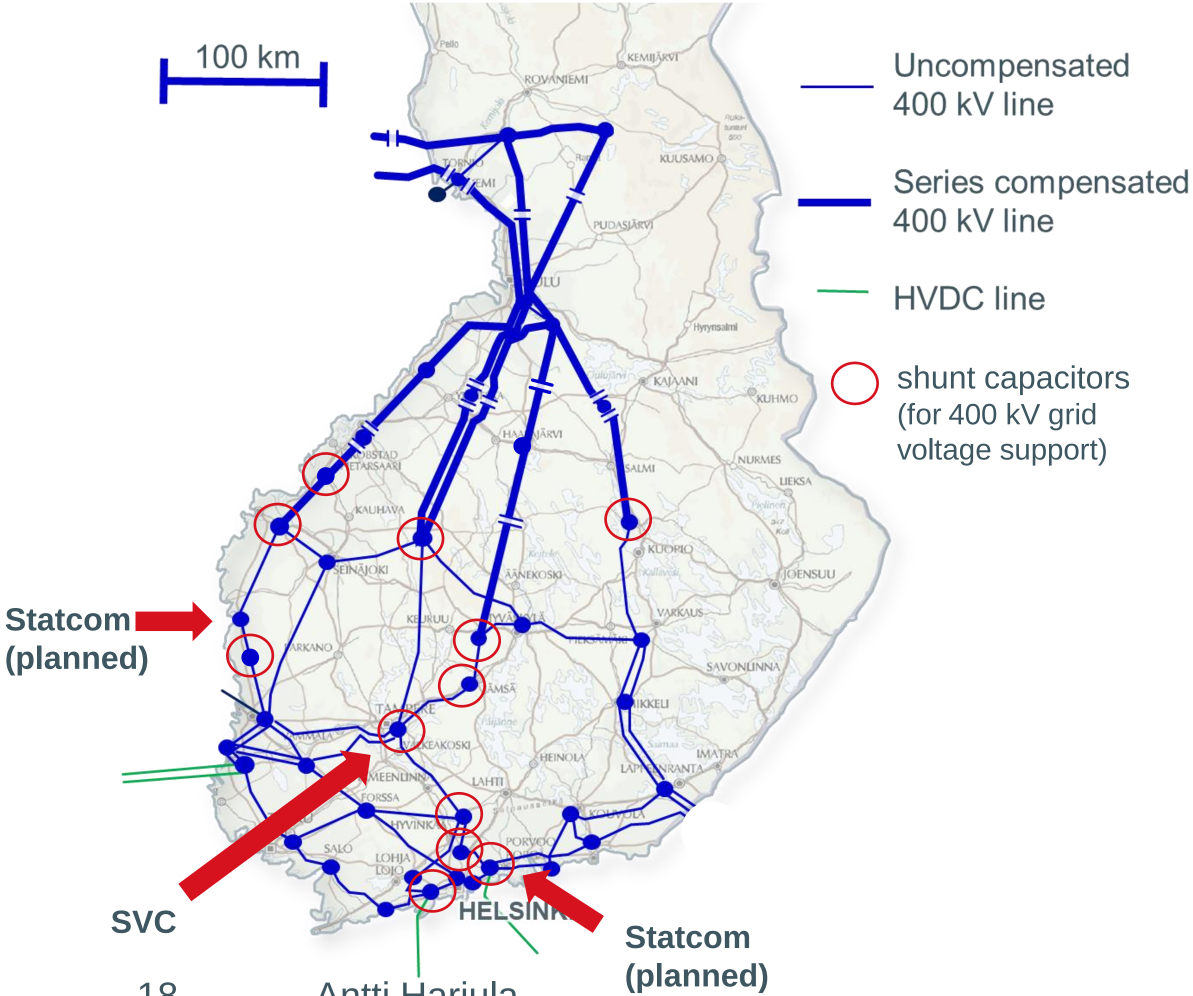
- Most power consumption is in southern Finland

- Typically, voltage stability limits the transfer capacity from north to south

- Fossil fuel based thermal power plants being decommissioned in southern Finland

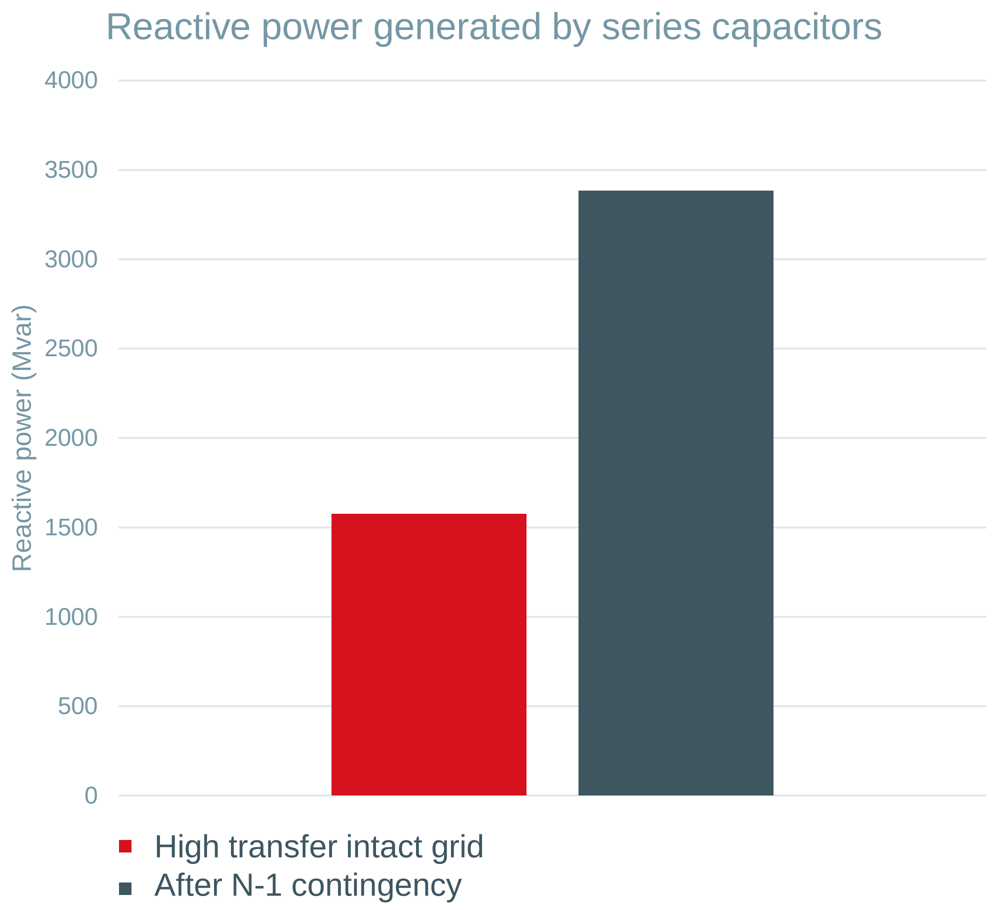


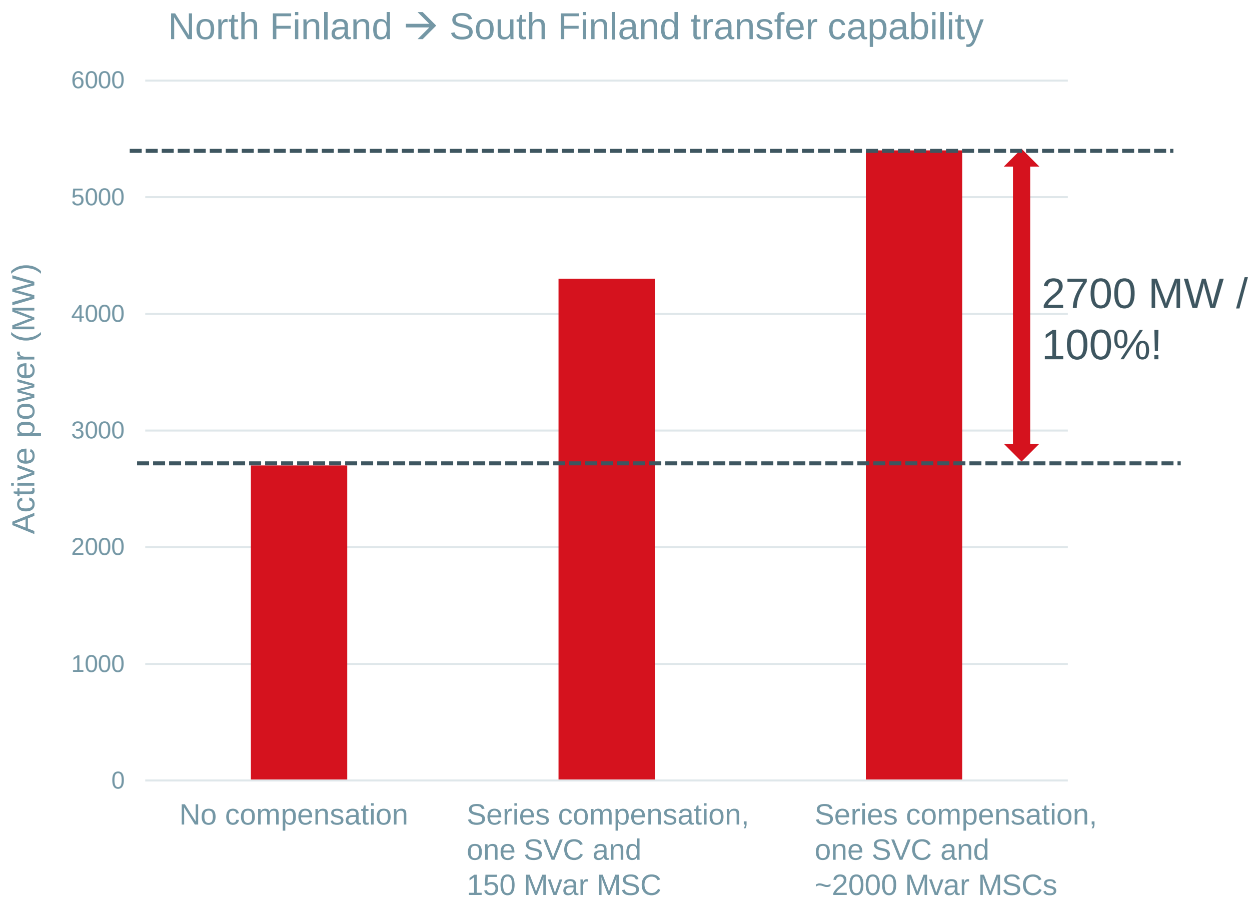
Voltage stability – solutions



- **Static voltage support**
  - Series capacitors in northern Finland (13 pcs)
    compensation degrees ~75% of line reactance
  - Shunt capacitors in southern Finland
- **Dynamic voltage support**
  - Series capacitors in northern Finland (13 pcs)
  - SVCs, HVDC VSCs and STATCOMs in southern Finland
  - Voltage control required from all power plants larger than 1 MW
    - (including wind power, solar power & BESS)

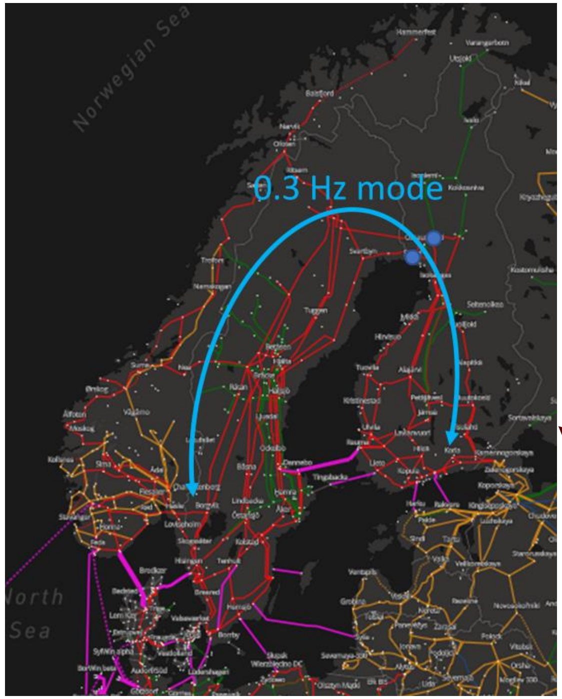
Impact of series and shunt compensation on transfer capability from north to south





Rotor angle stability

Rotor angle stability – Small signal - introduction of new large unit

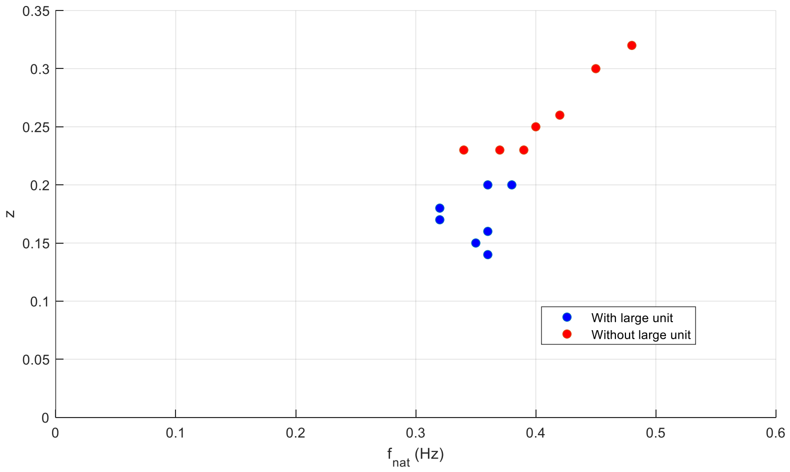


Inter-area power oscillations where generator groups oscillate against each other are typical in the Nordic power system and affect transmission capacity.

Generators in southern Finland oscillate against generators in southern Sweden and Norway through ~2000 km transmission path with a frequency of 0.3–0.4 Hz.

A new large generating unit (1992 MVA) which contributes at times to more than 10 % of the system total kinetic energy was commissioned.

The identified modal damping ratio as a function of the identified natural frequency of the mode in situations with and without the large unit.



Impact of a large synchronous unit on the oscillatory stability of the changing power system, Seppänen J., Haarla L., Kuivaniemi M. & Harjula A., CIGRE Symposium Cairns 2023

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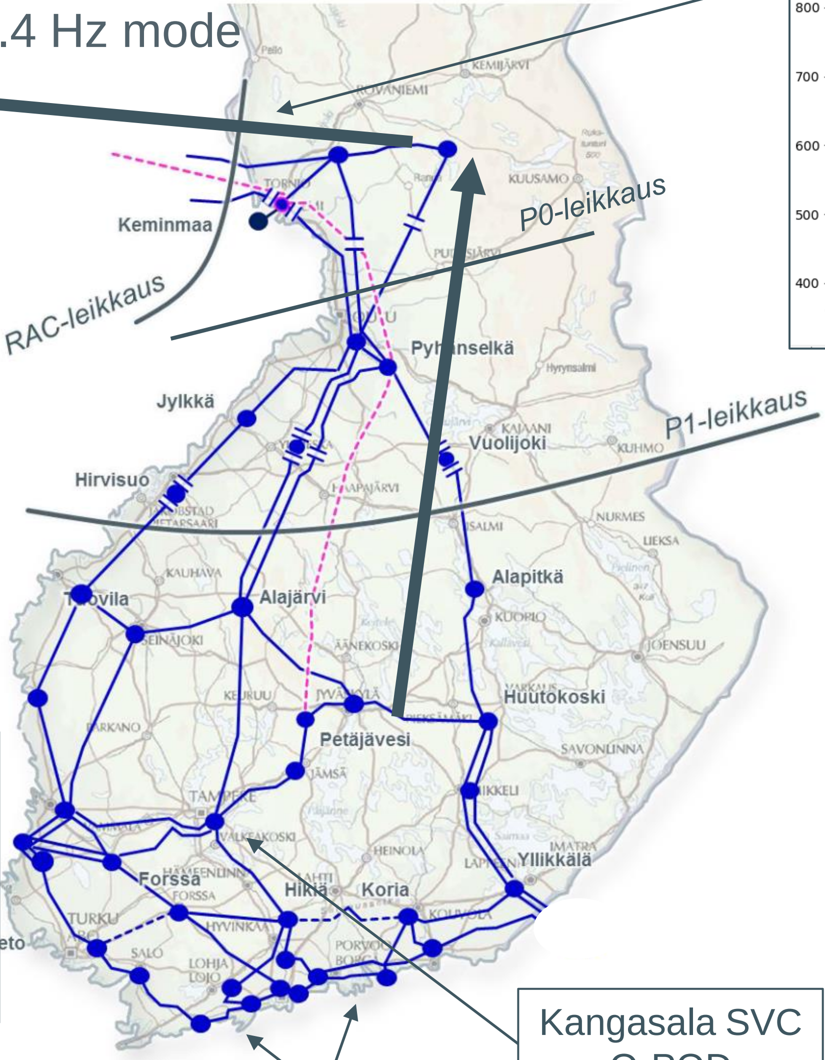
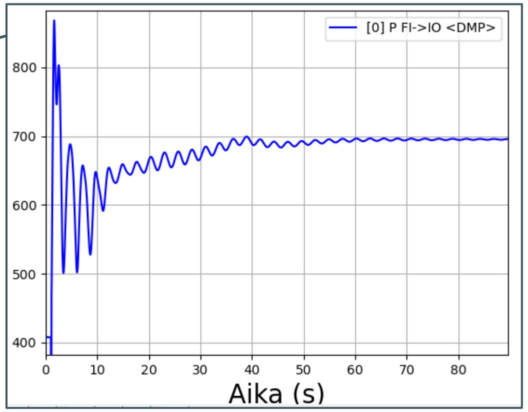
Rotor angle stability – Small signal

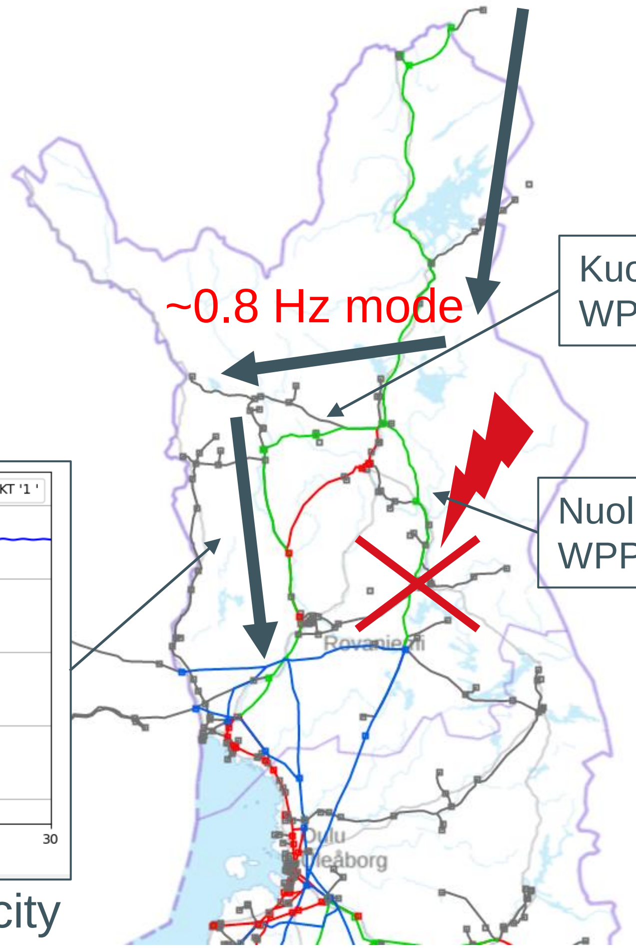
NORDIC
0.3-0.4 Hz mode





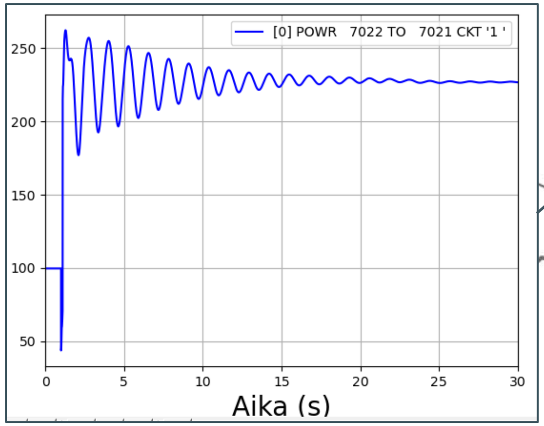
Limiting export capacity
Finland → Sweden

FI-NO



Kuolavaara
WPP w/ Q-POD

Nuolivaara
WPP w/ Q-POD



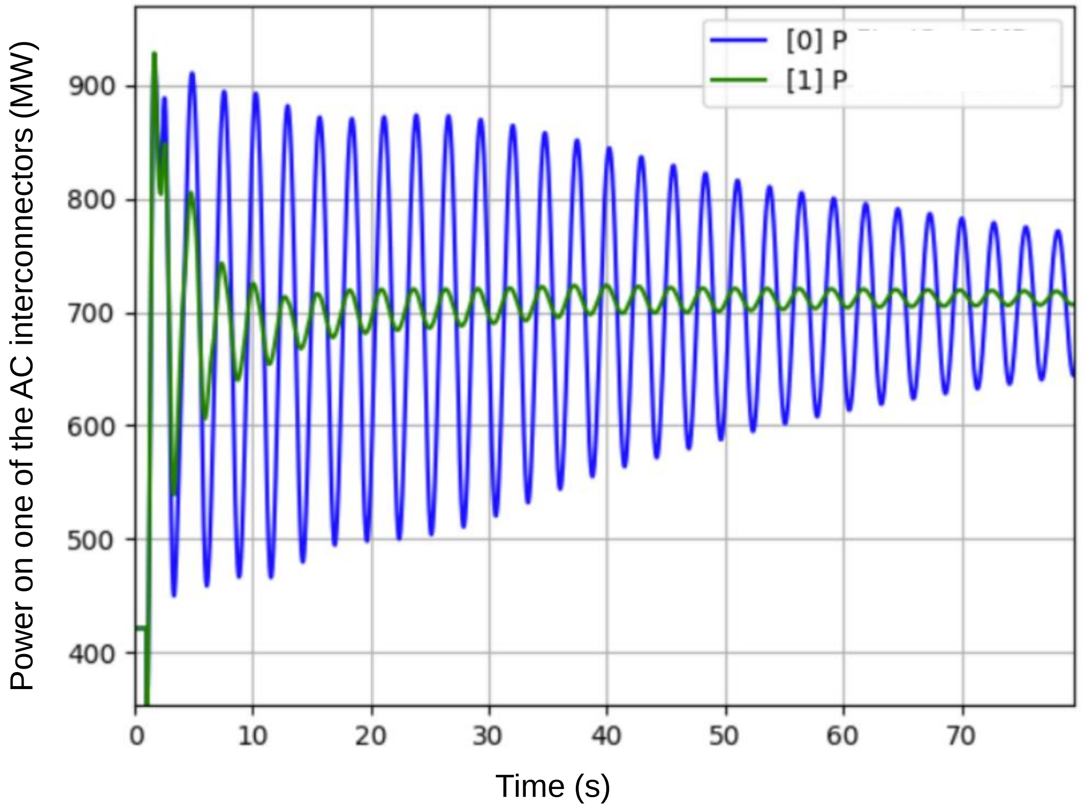
Limiting import capacity
of Norway → Finland

All large generators have PSSs tuned to damp inter-area oscillations

Kangasala SVC
Q-POD

EstLink 1&2 HVDC
P-POD

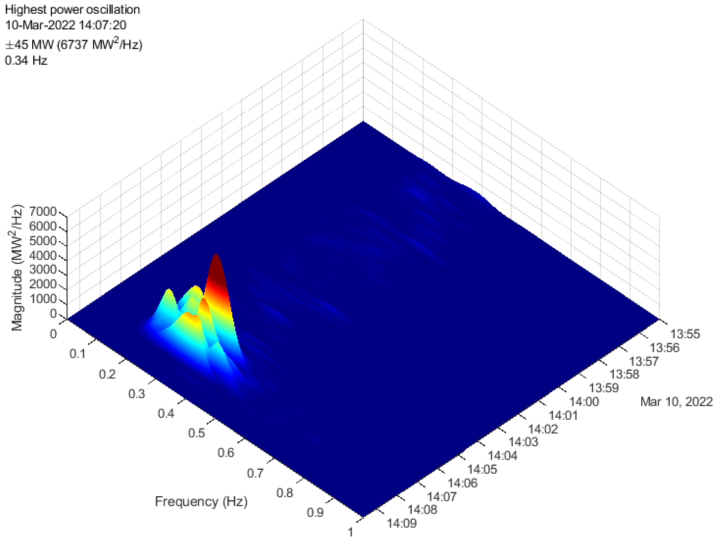
Impact of series compensation and POD controls on south to north & export to Sweden transfer capability



- Impact of series compensation from south to north transfer capability is more than 1000 MW
- Example of active component damping impact: Kangasala SVC POD control impact on export capability is 500 MW

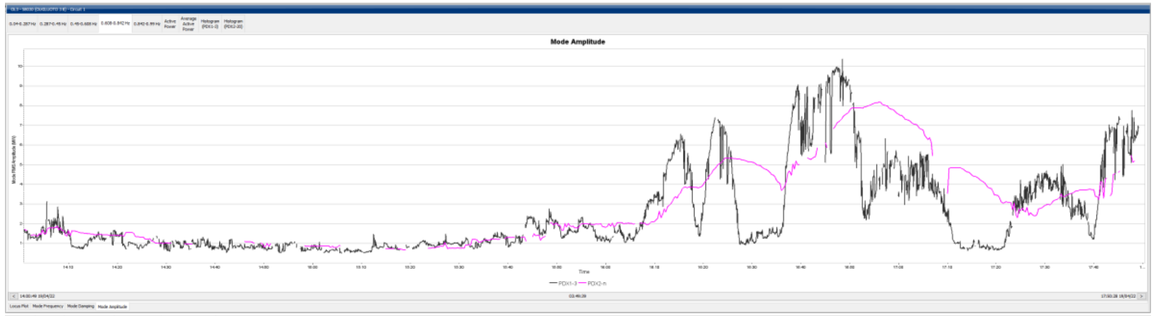
Rotor angle stability monitoring

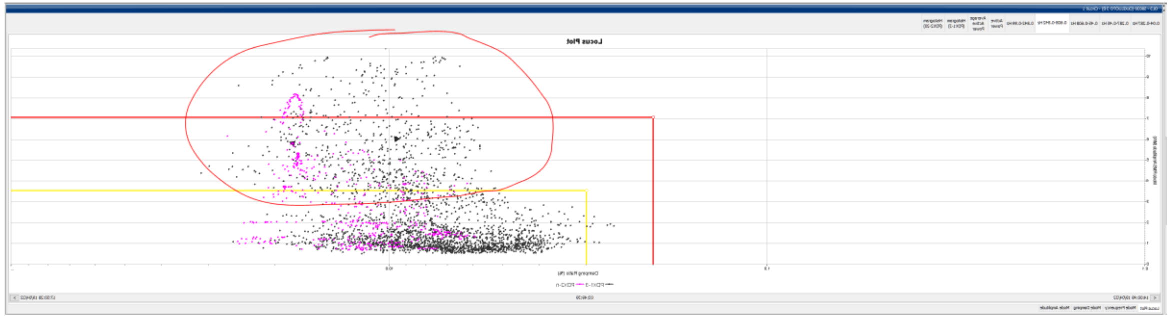
- Virtual supervisor monitors frequency, voltages and flows. Damping and system dominant inter-area mode frequency is calculated from interconnectors AC flow



- Dynamic supervisor semi-real time dynamic RMS simulations

- WAMS system analyzing all PMU signals





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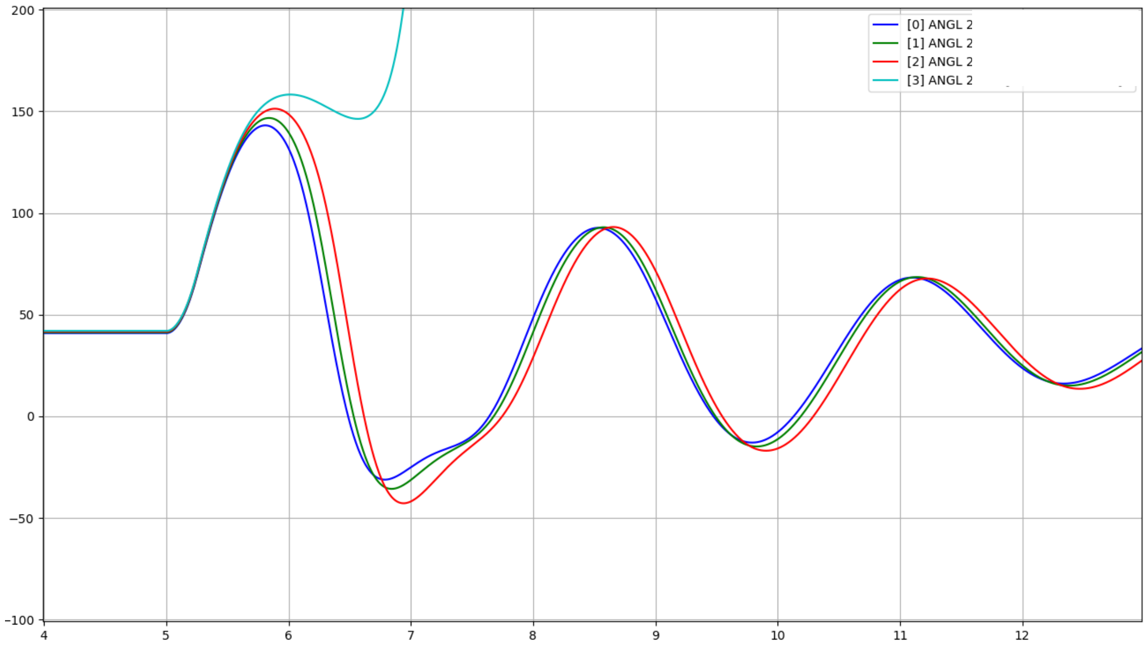
Rotor angle stability – Transient

Grid code describes the LVRT capabilities that must be fulfilled

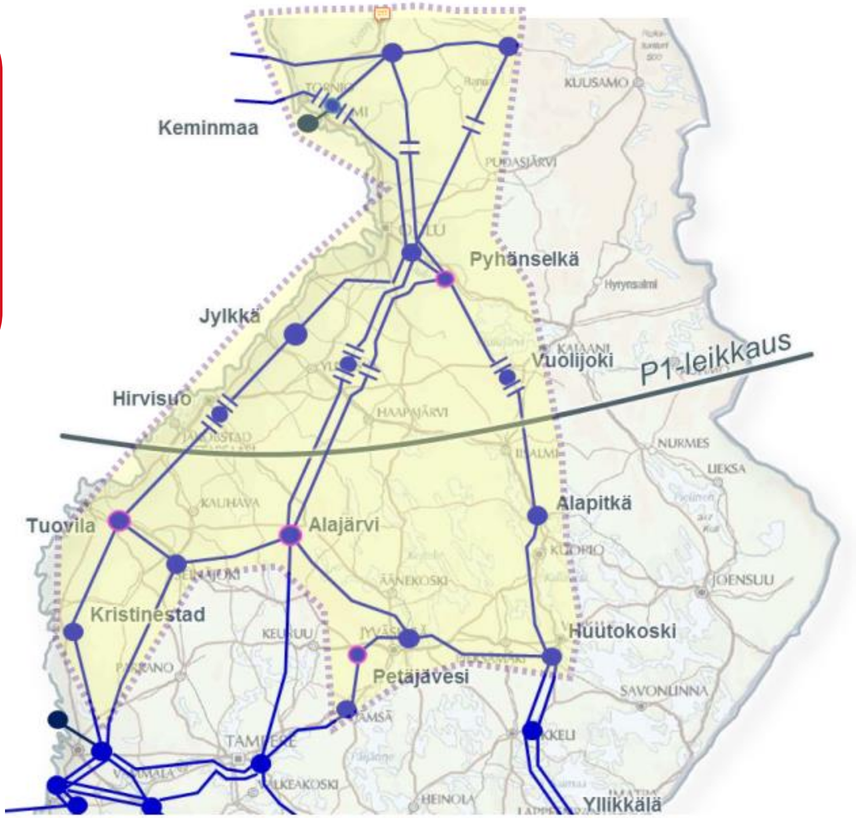
- Capability is confirmed with simulations by the vendor in SMIB
- For some power plants this is confirmed in dynamic simulations with Nordic Model
- In some special cases this is confirmed with real life short-circuit test



Resonance stability

Resonance stability - Electrical

Risk of SSO in the series compensated part of the grid especially with DFIG WPPs



Requirements applicable for converter connected units in yellow area

Series capacitors:

- Protection based on bandpass filtering

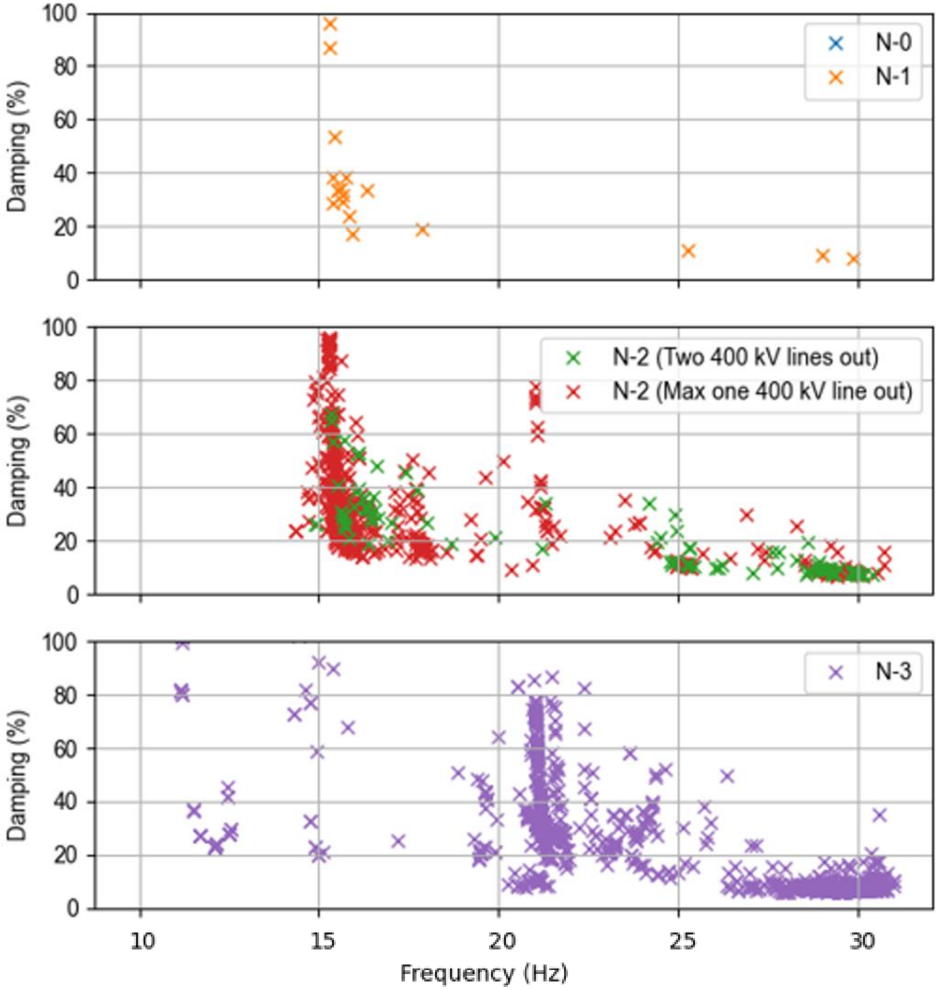
Converter connected units:

- Protection requirements
- Damping requirements
- Modeling requirements
- Instrumentation requirements

https://www.fingrid.fi/globalassets/dokumentit/en/customers/grid-connection/specific-study-requirements-for-power-park-modules-connected-in-vicinity-of.pdf

Resonance stability - Electrical

Series resonances in JY110kV:



Damping studies

- Background studies: 1) Python script to study network resonances in RMS model, 2) Feasibility studies with generic WPP models, 3) Feasibility studies with manufacturer models
- Project specific studies:
  1) Validating the delivered EMT model and protection concept
  2) Assessing the risk based on network and device impedance scans
  3) Time domain studies with large scale EMT models with manufacturer converter models

[1] Janhunen, O-P., Korhonen, R., Linnamaa L., Kuusela, A., Rauhala, T. "Experiences on studies for subsynchronous oscillation risks of wind power plants connected in the vicinity of Finnish series compensated network", Wind Integration Workshop 2021, Berlin.

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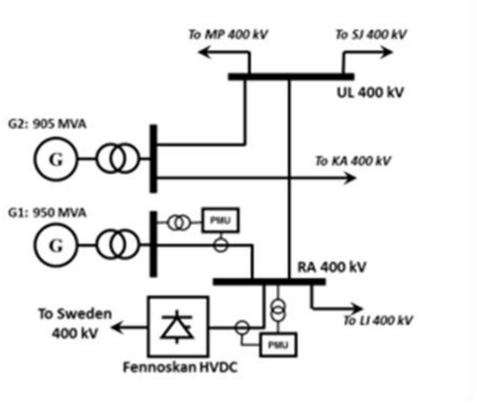
Resonance stability - Torsional

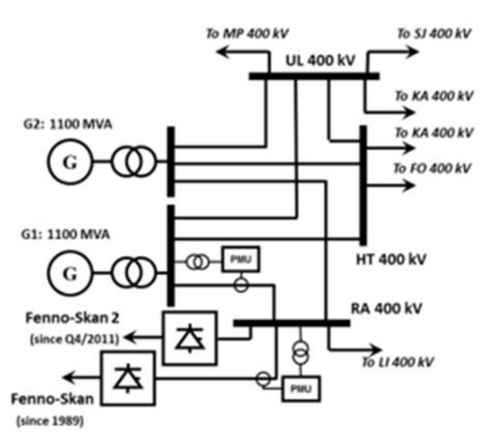
SSR and SSTI risk with large nuclear units interacting with series compensated grid or with HDC links

Turbogenerator in vicinity of HVDC LCC [A]

Grid topology in 2005

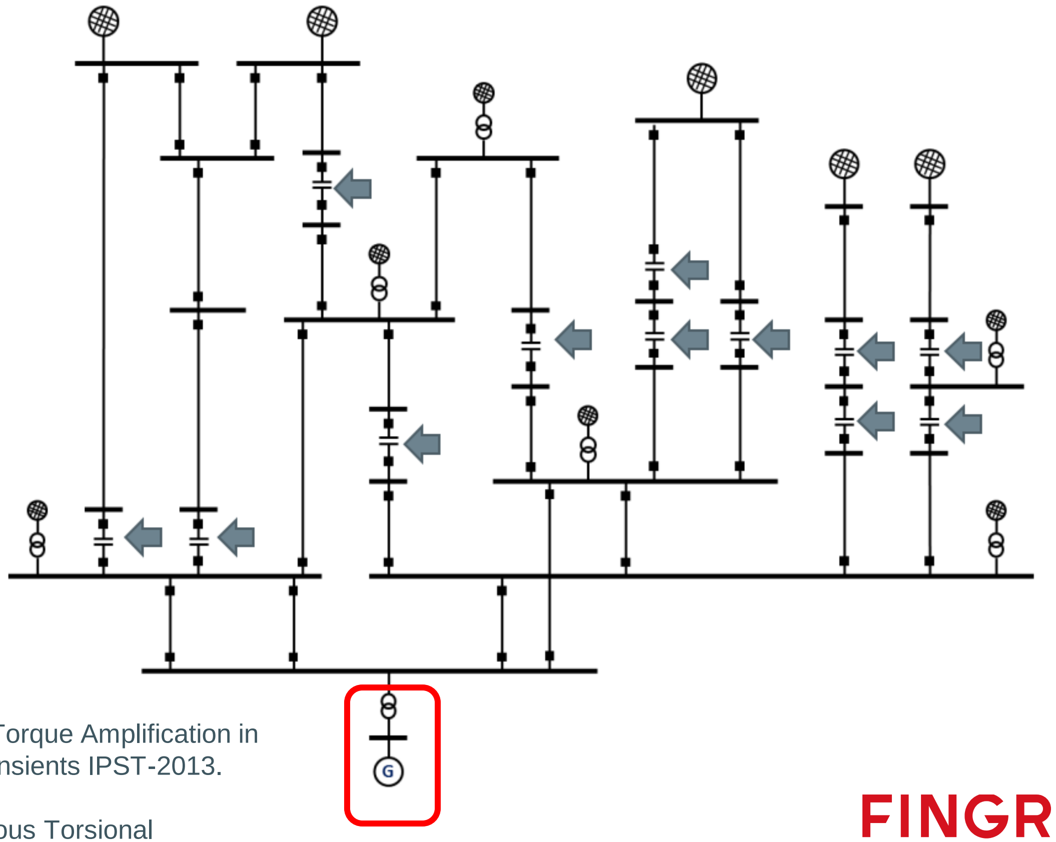


Grid topology after 2013



Different phases of structural changes in the Southwest part of Finnish 400 kV network

Turbogenerator in the middle of meshed series compensated system [B]



[A] Vuorenpää, P., Rauhala, T., Järventausta, P., Acha, E. 2013. On Assessing the Risk of SSR Related Torque Amplification in Series Compensated Networks. Proceedings of the 10th International Conference on Power Systems Transients IPST-2013. Vancouver, B.C., Canada. 6 pg. July 2013.

[B] Rauhala T.. "Frequency Domain Methods for Transmission Network Planning to Assess Subsynchronous Torsional Interaction due to High Voltage Direct Current Transmission System". Ph.D. Thesis. Tampere University of Technology. ISBN ISSN 1459-2045. Tampere, Finland. November 2014. 166 pages

Resonance stability - Torsional

Turbogenerator in vicinity of HVDC LCC

- Feasibility studies: 1) frequency scans, 2) EMT Damping torque and time domain analysis with Cigre BM model
- SSTI study was required from the **HVDC** manufacturer who based on the results introduced **a subsynchronous damping circuit (SSDC)**
- The sufficient damping has been validated with SAT tests, the post disturbance analysis has been made with PMUs and fault recordings

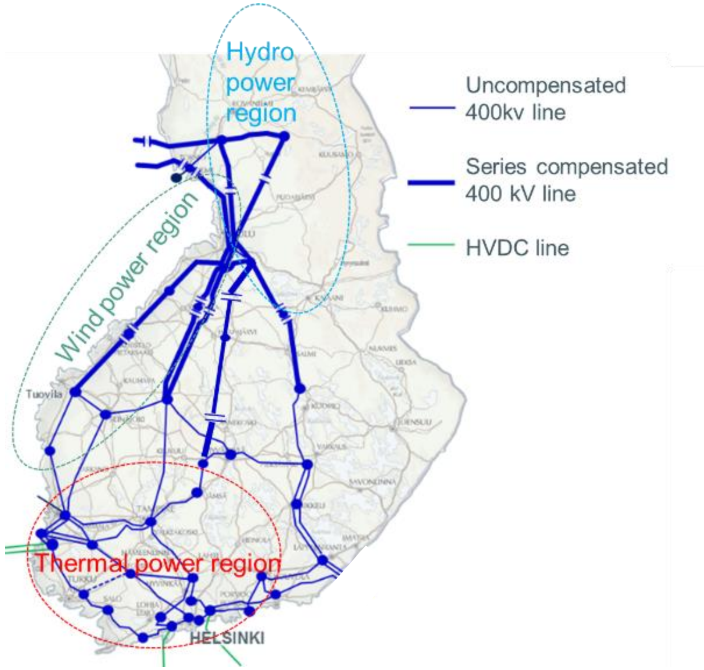
Turbogenerator connecting to series compensated system

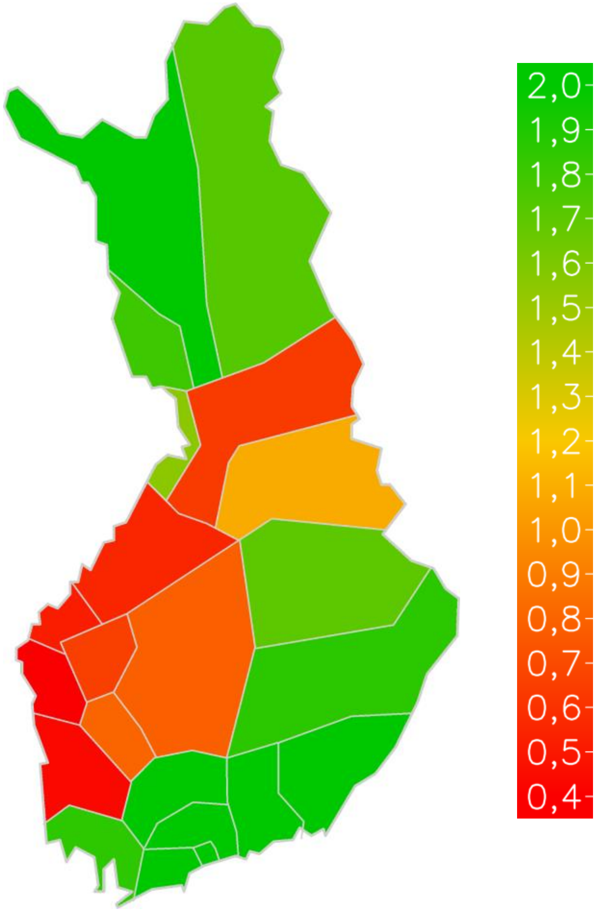
- Feasibility studies: 1) Frequency scans, 2) EMT analysis on Torque Amplification and Torsional Interaction
- EMT study included 1) Frequency scans, 2) Perturbation and 3) Time domain analysis

Large turbogenerators equiped with SSO monitoring (and if needed protection)

Converter driven stability

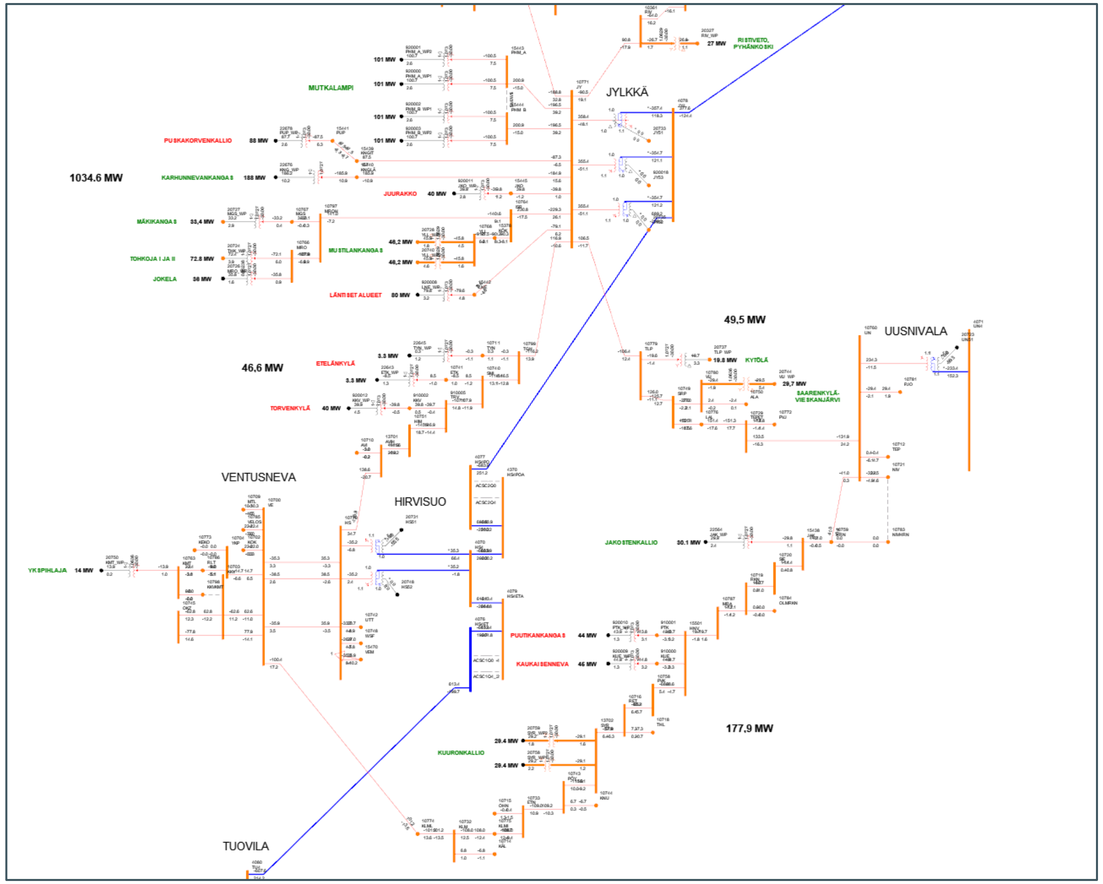
Converter driven stability risk screening





Average equivalent short circuit ratio (ESCR) of wind and solar power plants after worst contingency for each power plant in minimum synchronous generation case 2025

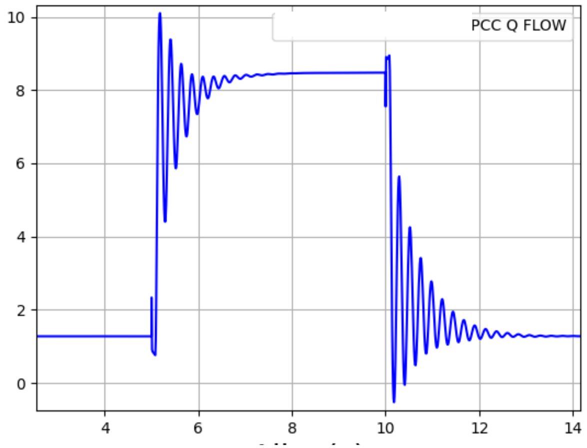
Converter driven stability – Slow interaction

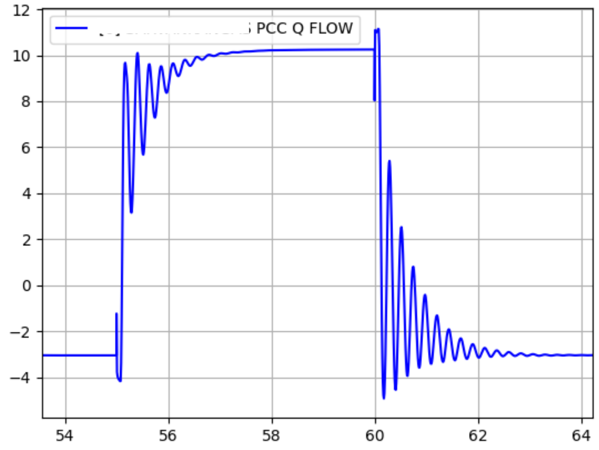


- It was found that the voltage controller tunings are not proper due to high share of converters in the west coast area and control mainly on plant level

  -> Large overshoot and even unstable oscillations of individual WPPs were observed in the simulations

- The tuning principles were changed from SCR to ESCR approach. Old wind power plants retuned.





https://www.fingrid.fi/globalassets/dokumentit/fi/palvelut/kulutuksen-ja-tuotannon-liittaminen-kantaverkkoon/fingrid---guidance-on-escr-and-voltage-control-tuning-2023_09_19.pdf

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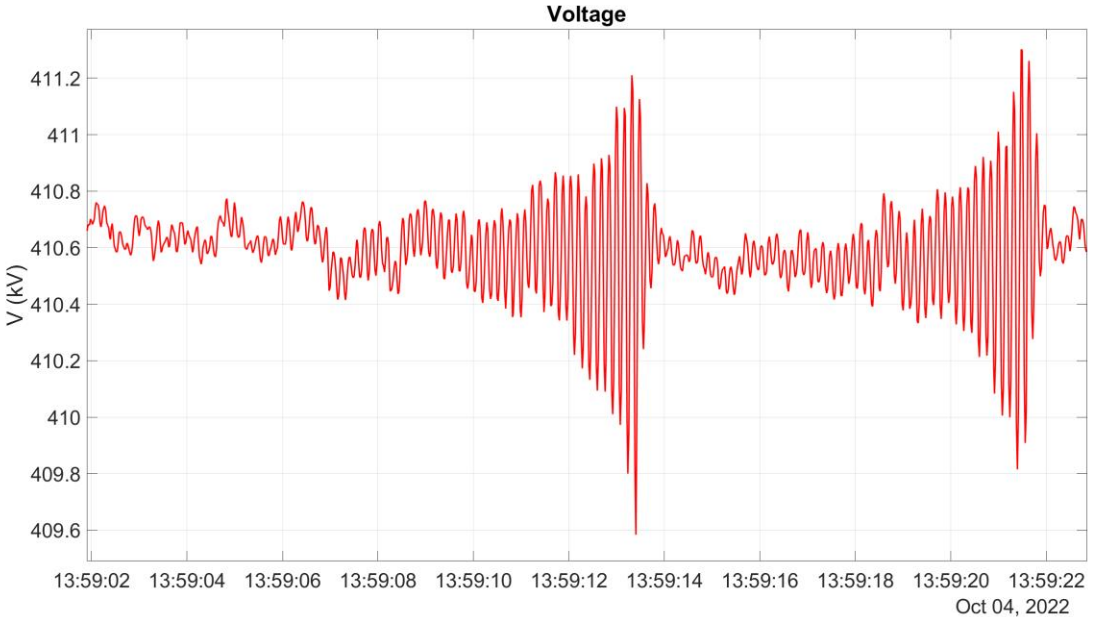
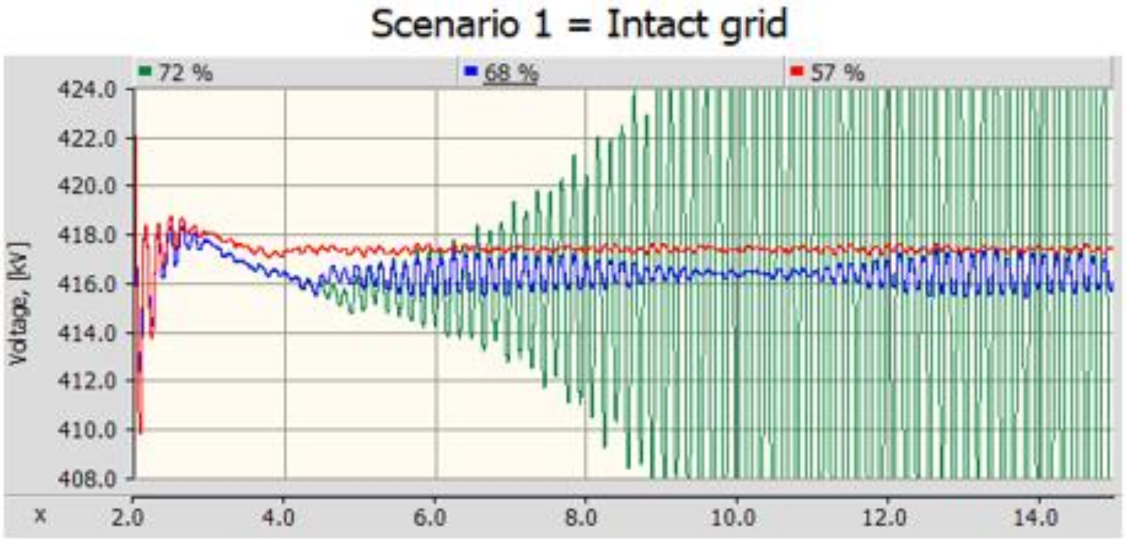
Converter driven stability issues emerging

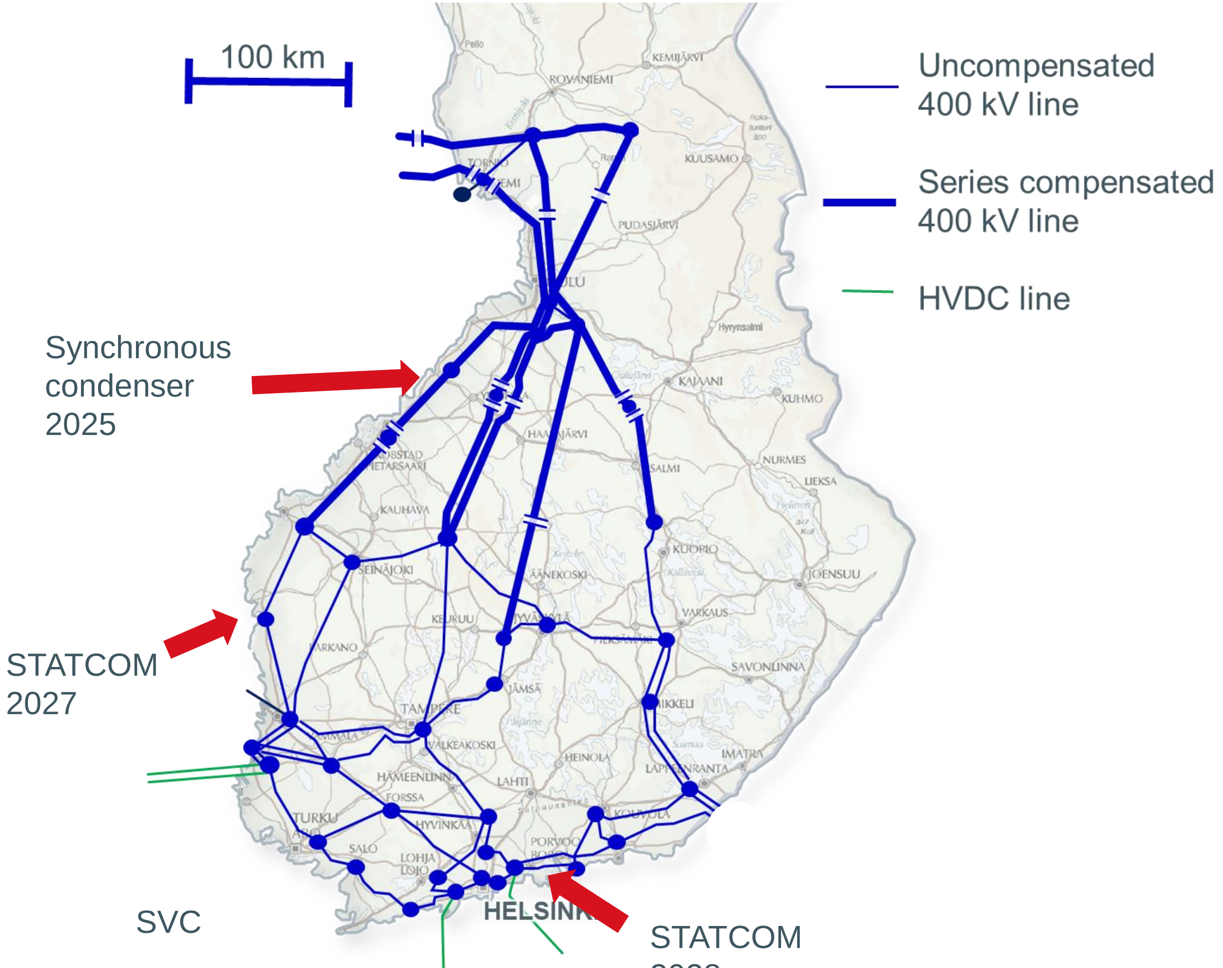


- PMU measurement for converter driven voltage oscillations in large meshed grid during outages, ~65 wind power plants and hundreds of wind generators participating



- Increased amount of wind power causing instability in simulations even with intact grid if no mitigation solutions are used

Converter driven stability – solutions



Basis has been to build modelling, study and monitoring capabilities, with those the following solutions were found effective and are taken in use:

- Retuning of WPP voltage controllers
- Very fast initial voltage response (~inverter level voltage control) required from new IBR
- Synchronous compensator
- STATCOMs with grid forming controls
- Grid forming control required from BESS
- Curtailing power, changing reactive power mode
- New monitoring capabilities, more PMUs and WMUs

Conclusions

Conlusions

- Finnish power system is changing more rapidly than ever: more than 5 GW of new generation connected during just last two years to a system with minimum load of 6,5 GW. Last year 95% of generation was already carbon neutral, still decarbonizing the whole society requires a lot more renewable generation.
- Sometimes power is almost 100% synchronous machine generated and in couple of years sometimes its 75 % IBR generated, and by 2030 sometimes 90 % IBR generated
- Traditional stability phenomena still needs to be considered while new stability phenomena requires new solutions
- Modelling, studies, operation and monitoring are all becoming more complex and resource intensive
- Solutions exist, while a lot of innovation still needed to enable the complete carbon neutrality transition in cost efficient way → from stability perspective grid forming controls of all IBR types is most crucial

This is the most interesting time to be an electrical and energy engineer as we can save the world.

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