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Grid Oscillations and Hydropower Operations

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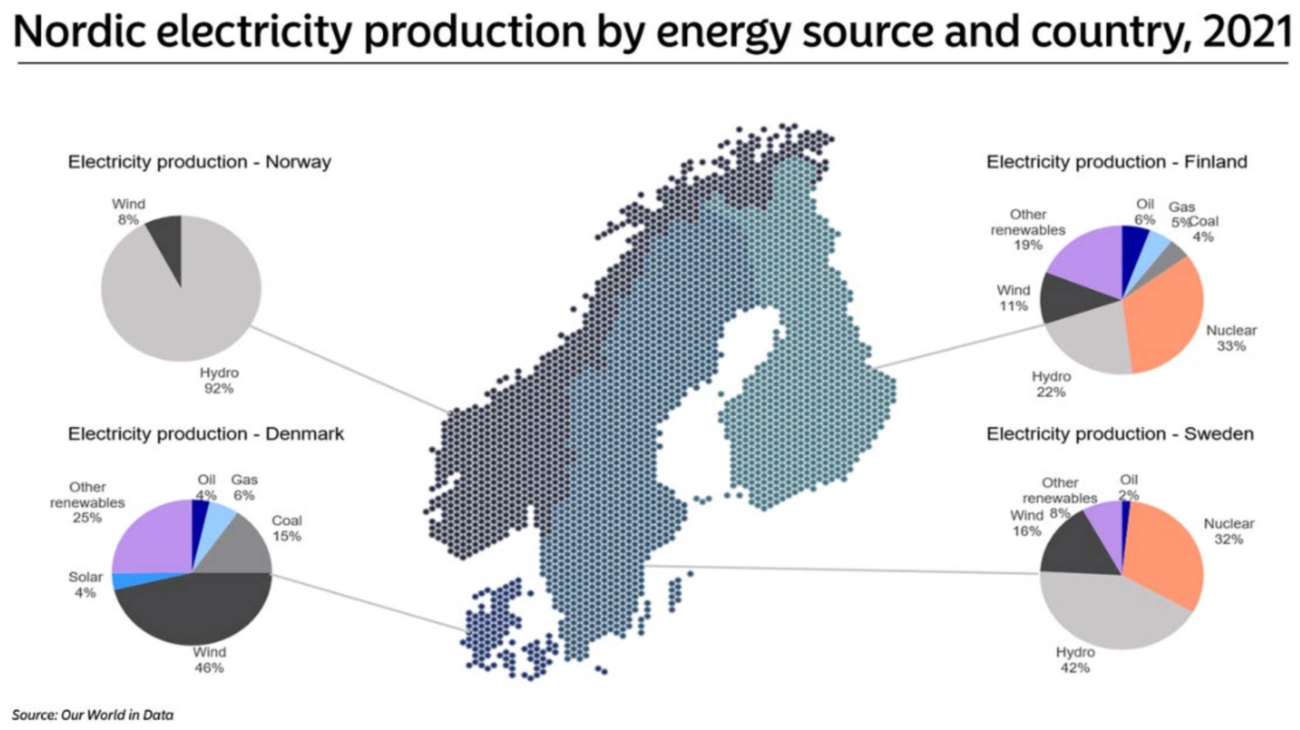
Project Overview

Background:

- The grid is changing (generation mix, large electric loads, etc.) and so is its dynamics.
- System operators have limited understanding of how hydrological conditions impact the dynamic behavior of hydropower plants and grid oscillatory stability.
- The DOE WPTO is funding an effort to investigate how the oscillatory behavior will be impacted by hydro-operations.
- Knowledge share among PNNL and Norwegian universities – NTU and UiA.



Norway generation primarily comprises hydro and wind. Thus, the Nordic grid provides a forward-looking benchmark that US power system planners and operators can study and learn from.

Overarching questions:

- How will changing generation mix and different hydrological conditions impact oscillations in the future grid?
- How can hydro-units be leveraged to mitigate oscillations and improve grid stability and reliability?
- How can slow-acting hydro and fast acting-inverters be optimally coordinated to ensure grid stability?
- What can US power system operators learn from the Norwegian experience?

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Risks Associated with Oscillations

Frequency	Behavior of Hydro-resources	Interaction with Other Grid Components	Research Gaps
< 0.1 Hz **Ultra low-frequency oscillations (ULFO)**	▪ Negative damping from mistuned hydro-governors and water-hammer effect in hydro-turbine	▪ Emerging risks from forced oscillations induced by slow-periodic AI loads in data centers	Challenging to isolate ULFO from changes due to redispatch/other operations
0.1 – 2 Hz **Electro-mechanical range**	▪ Hydrological conditions impact damping of inter-area and local modes ▪ Forced oscillations induced by rough zone operation	▪ Forced oscillation resonance with poorly-damped system modes	Representing hydrological conditions in planning cases
> 5 Hz **Sub-synchronous oscillations (SSO)**	▪ Excitation of torsional modes induces shaft stress in hydro-turbines ▪ SSOs from variable speed hydro	▪ Torsional interactions from large load-induced oscillations ▪ Control interactions with other power electronic resources	Understanding the impact of LL-induced oscillations on torsional modes

Impact of Hydrological Conditions on Oscillation Modes

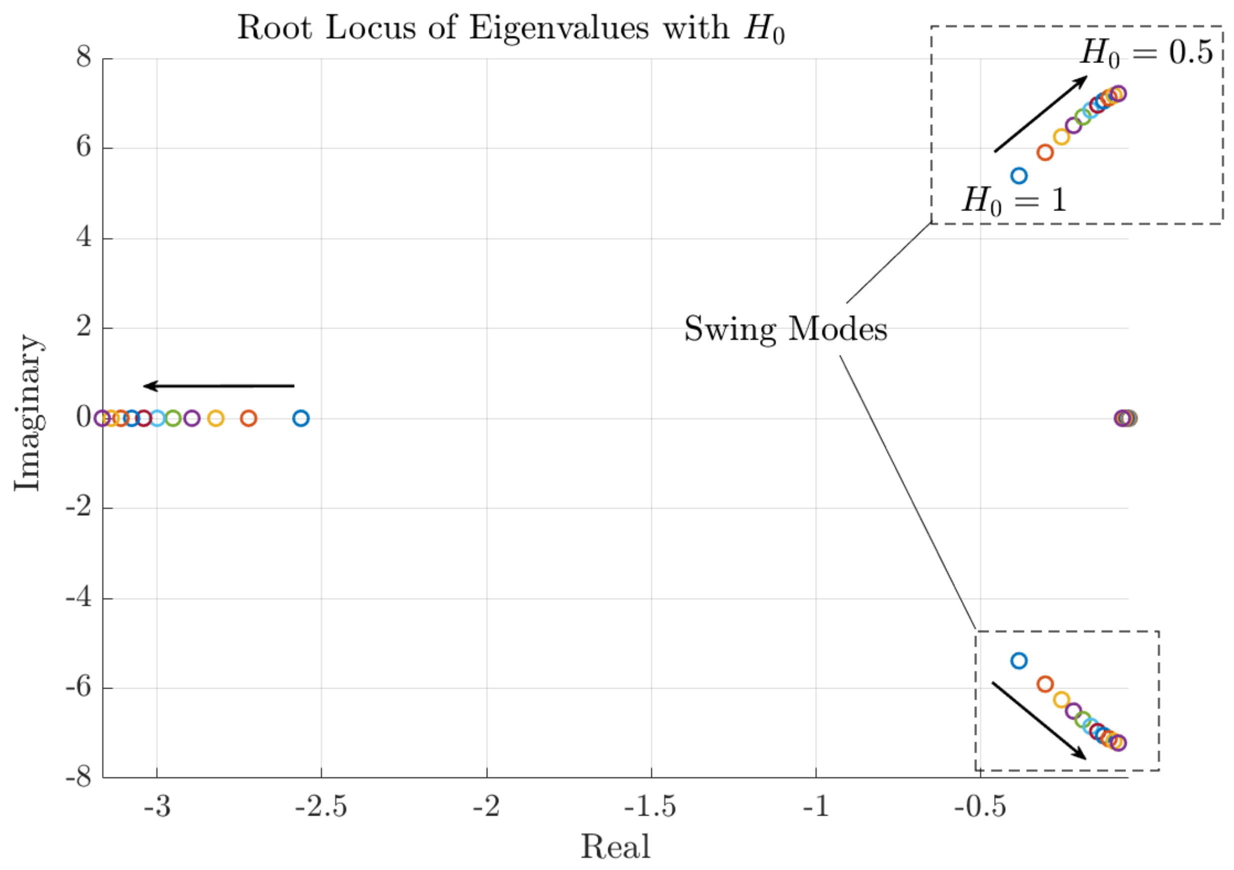
- Varying waterhead impacts system dynamics in two ways –
  - Impact of waterhead on machine swing dynamics (**system-independent**)
  - Impact of generator redispatch (**system-dependent**)

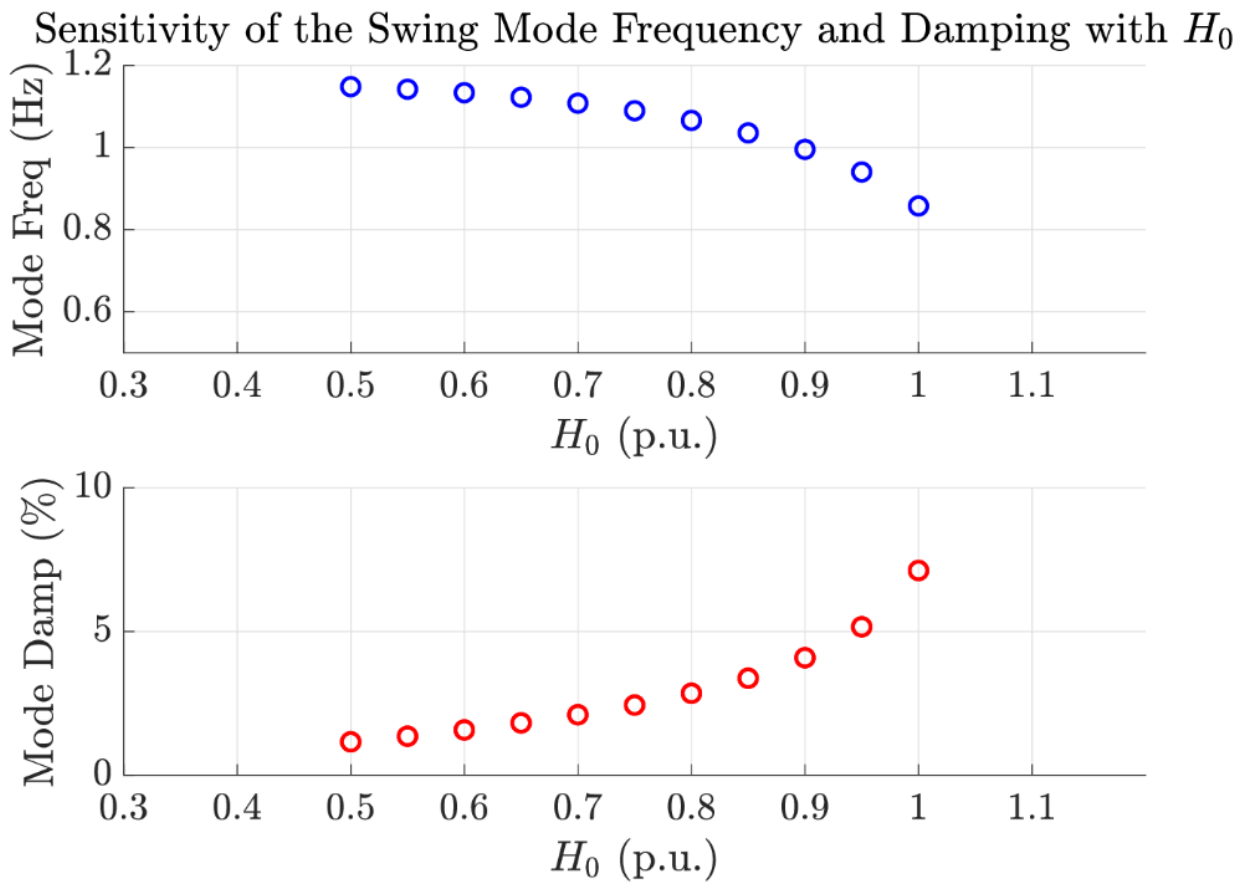
- How varying hydrological conditions will impact oscillatory behavior will depend on both factors, making generic conclusions difficult.

- Not incorporating hydrological conditions into planning cases may lead to incorrect conclusions about grid stability.

Impact of Water Head on Swing Mode

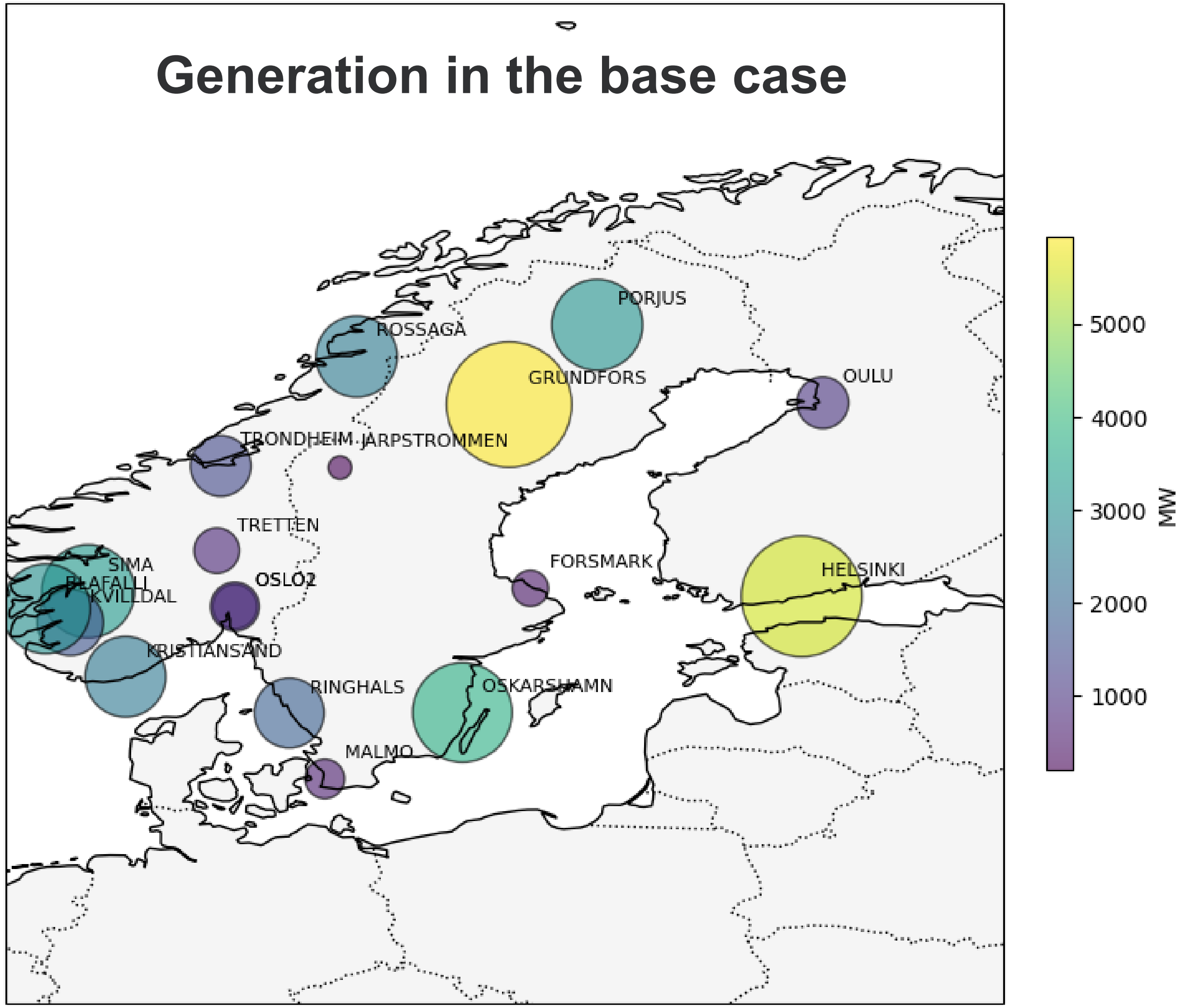
- Single Machine Infinite Bus representation.





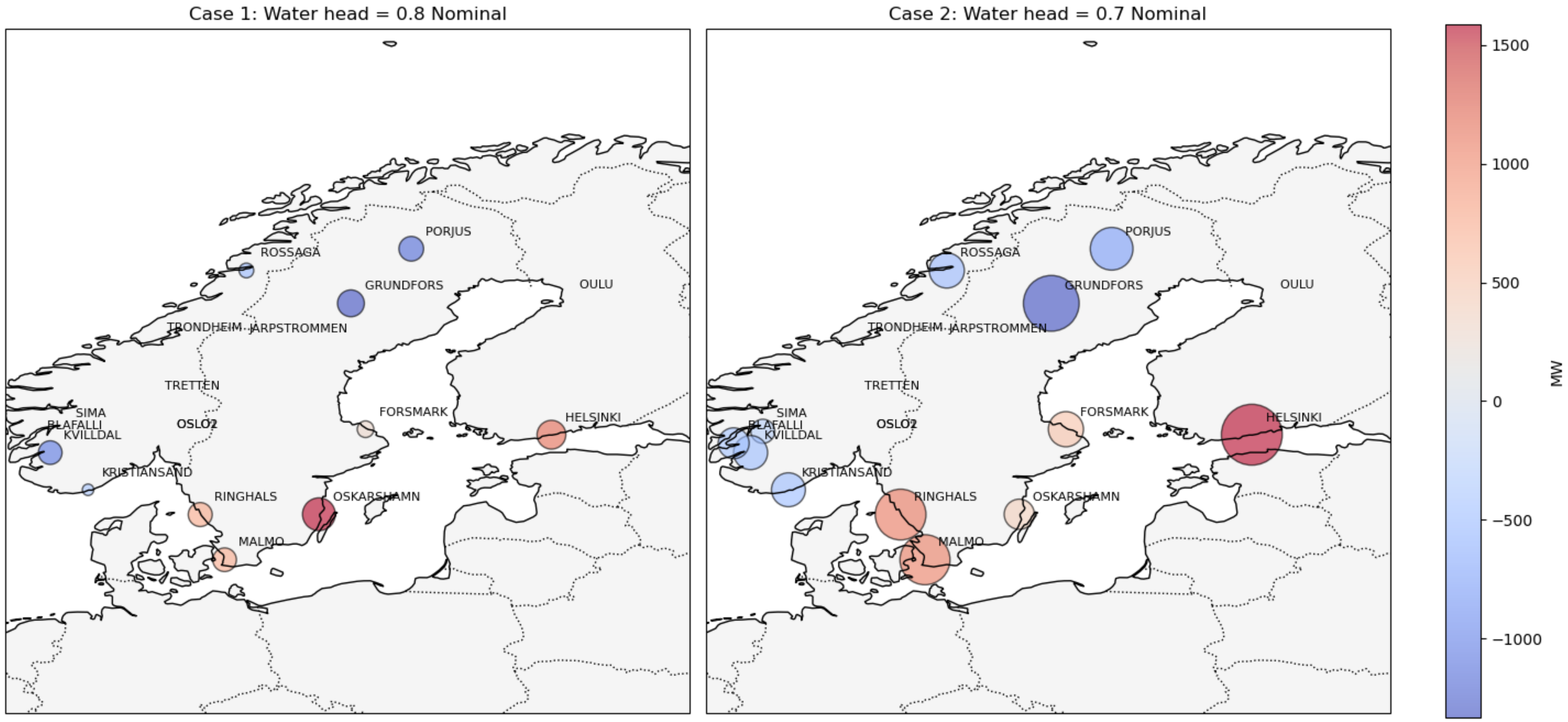
Impact of Varying Waterhead on the Nordic Grid

- PSLF studies on the reduced Nordic44 grid model
- Hydro-governors represented by HYGOV model
- Model comprises - 80 generators and 48 loads
- Total generation: 39.2 GW, Hydro share: 27 GW
- For many hydro units, Pgen well below Pmax



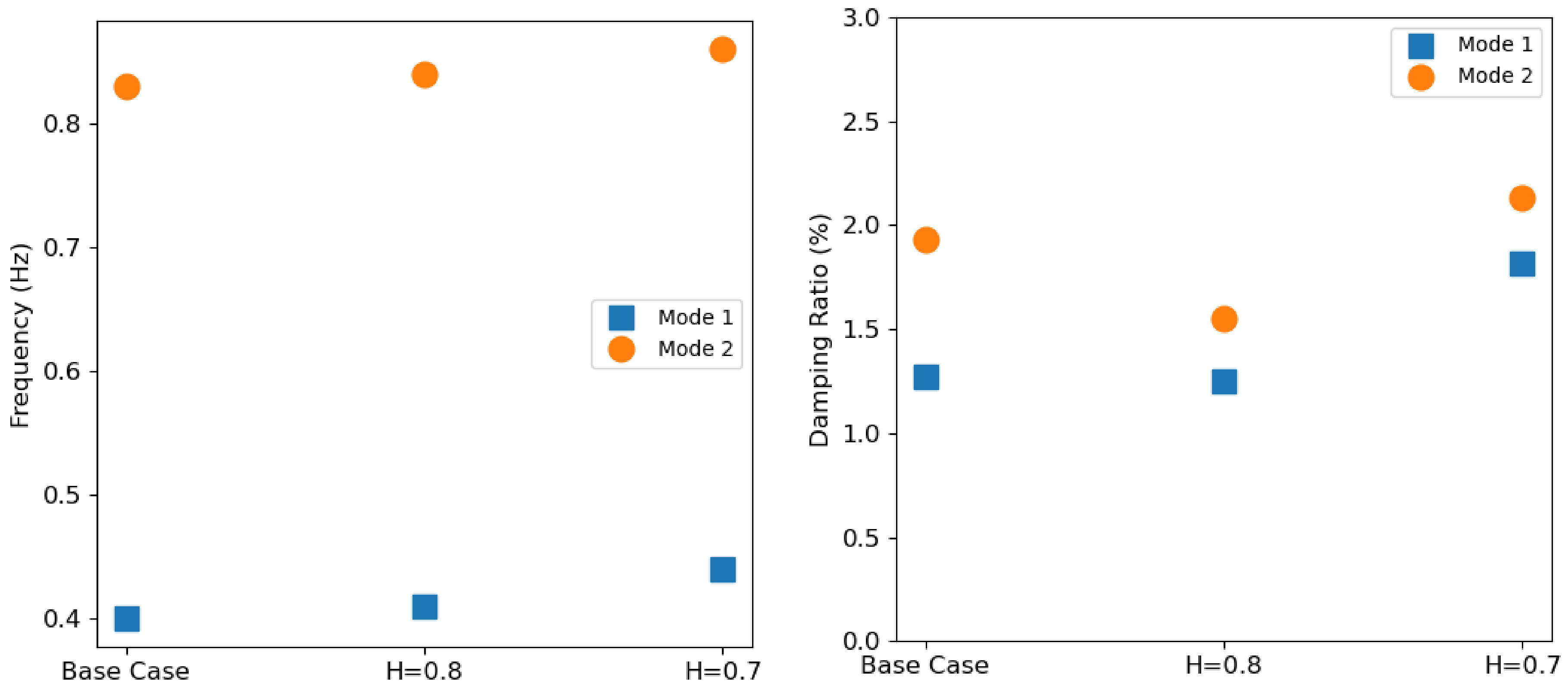
Simulated Hydrological Conditions

- Two cases created – water head varied to 80% and 70% of nominal; headroom maintained at 20%
- Reduction in hydro-output compensated by non hydro units



Generation change from the base case. Blue indicates decrease, red indicates increase. Circle sizes proportional to change.

Observed Changes in Oscillation Modes



- Increasing trend in frequency.
- Trend not clear in damping ratio – obscured by power flow changes.
- In this work all non-hydro units have been proportionally redispatched. It will be important to check realistic redispatch.

Next Steps

- Study with the WECC-240 bus system and full WECC model
- Model and scripts to be made publicly available
- Studying the impact of interactions between emerging resources and hydro-units
- Oscillations in sub-synchronous range

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Thank you

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