31783 - Integration of wind power in the power system

Quantification of the Equivalent Synchronous Rotating Inertia Available from Synthetic Inertia Response of Wind Turbines

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Agenda

- Motivation
- Theory
- Methodology
- Results
- Discussion
- Conclusions

Motivation

- Modern wind turbines (type C and D) are interfaced to the grid via converters.
  - No natural inertial response.

- Inertia and inertial response is lost when a conventional power plant is removed.
  - Wind turbines with a Synthetic Inertia Controller can provide an inertial response.
  - How many wind turbines with SIC are necessary to compensate for a conventional generator, such that the initial RoCoF following a transient disturbance is unchanged?

- This is valuable information for a TSO to ensure the initial RoCoF is not worsened when replacing conventional power plants with wind turbines.

Theory

- The swing equation in p.u. for a single generator:

$$\frac{d\omega_{m,pu}}{dt} = \frac{(P_m - P_e - D \cdot (\omega_{m,pu} - \omega_{0,pu}))}{2H}$$

- Synthetic inertial response from a single wind turbine is given by:

$$P_{e,SIC} = \omega_{m,pu} \cdot K_{SIC} \cdot \frac{d\omega_{m,pu}}{dt}$$

- Inserted in the swing equation, then the modified swing equation for a single generator in p.u. becomes:

$$\frac{d\omega_{m,pu}}{dt} = \frac{P_m - P_e}{2H + \omega_{m,pu} \cdot K_{SIC}}$$

- Note in the above only a single wind turbine is considered, the contribution from N wind turbines would result in: $N \cdot \omega_{m,pu} \cdot K_{SIC}$

Methodology

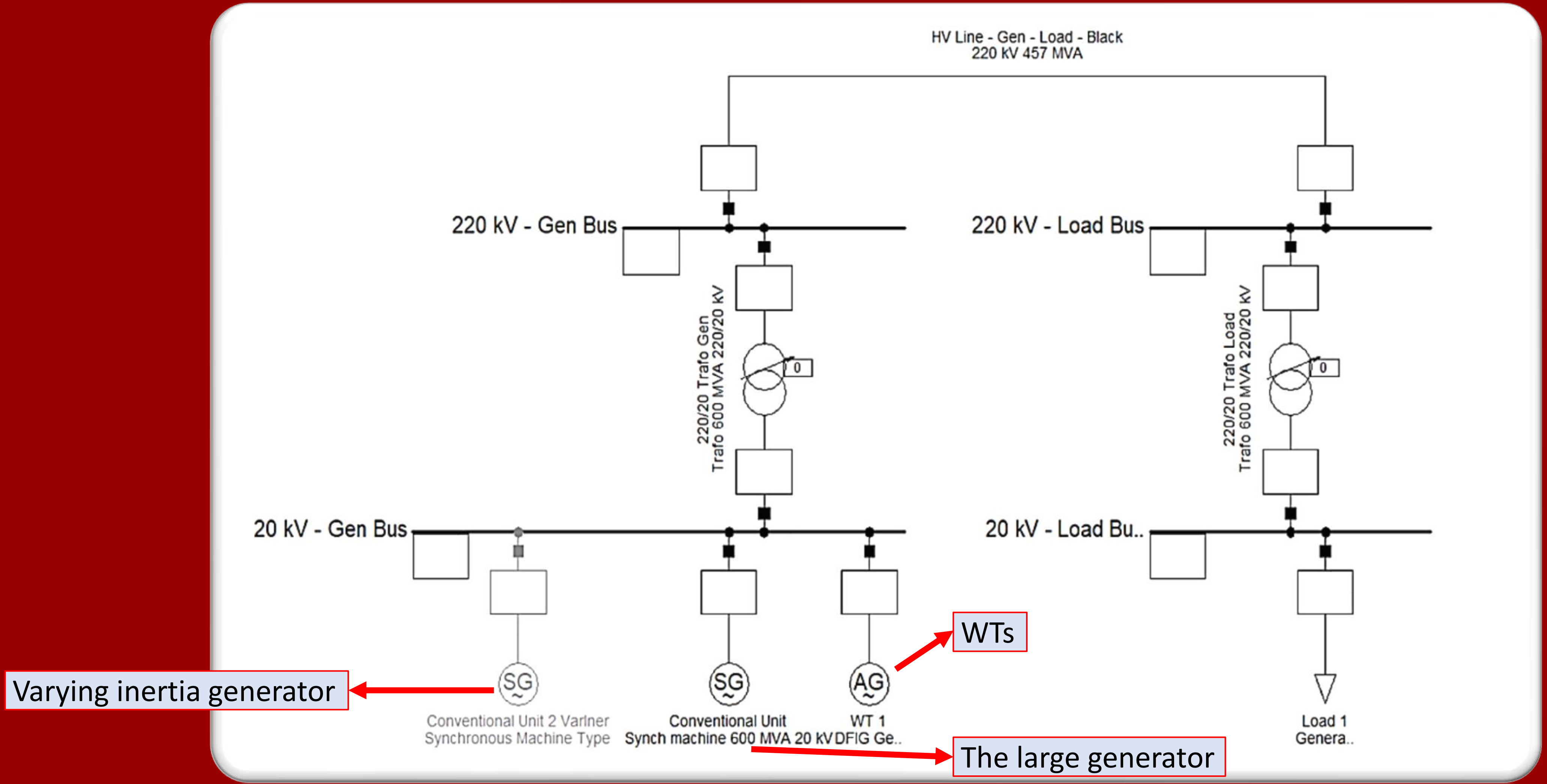
In the radial grid the following cases are considered:

- **Base case:** both the large (600 MVA, 5.75 sec) and the smaller generator (100 MVA, with varying inertia constant H, 2-8 sec) are connected.
- **Reduced inertia case:** only the large generator is connected.
- **WT support (and reduced inertia):** large generator and number of wind turbines equipped with SIC in order to achieve the same RoCoF.
- $K_{fast} = 8$ for robustness.
- Wind speeds: 0.3, 3, 4.8 and 6 MW per WT.

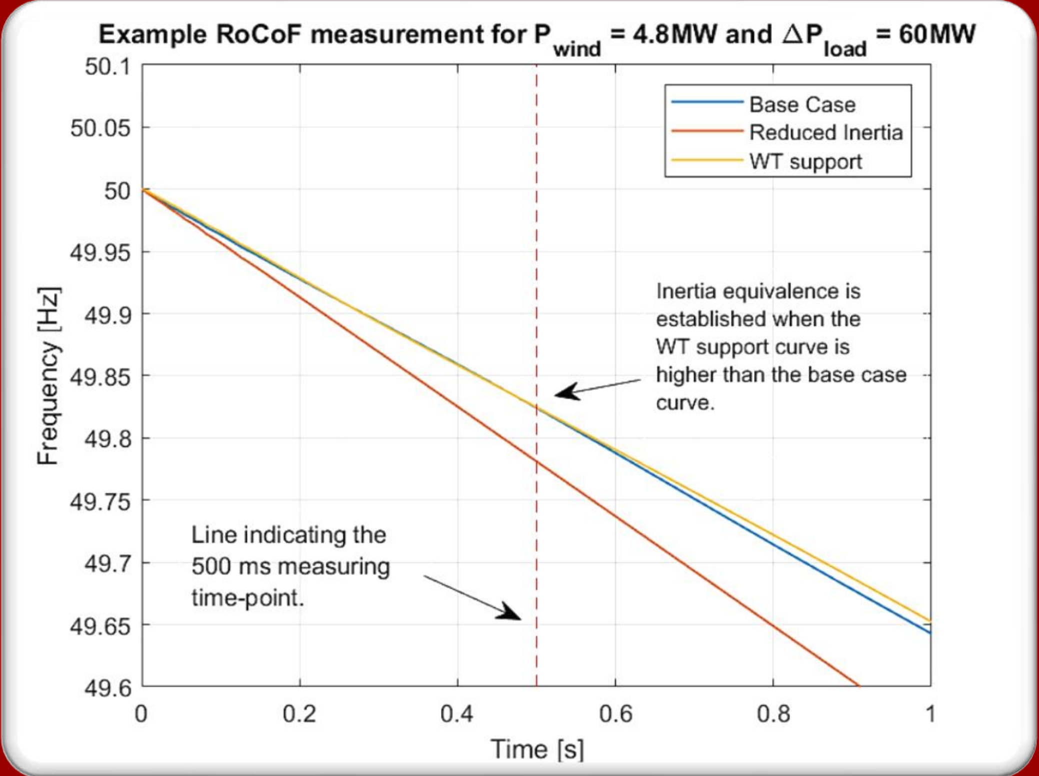
H = 2, 4, 6, 8

- RoCoF measurements for each inertia reduction (2-8 sec) and different load steps 20-100MW (in steps of 20 MW).
- Test and validation on the meshed grid.

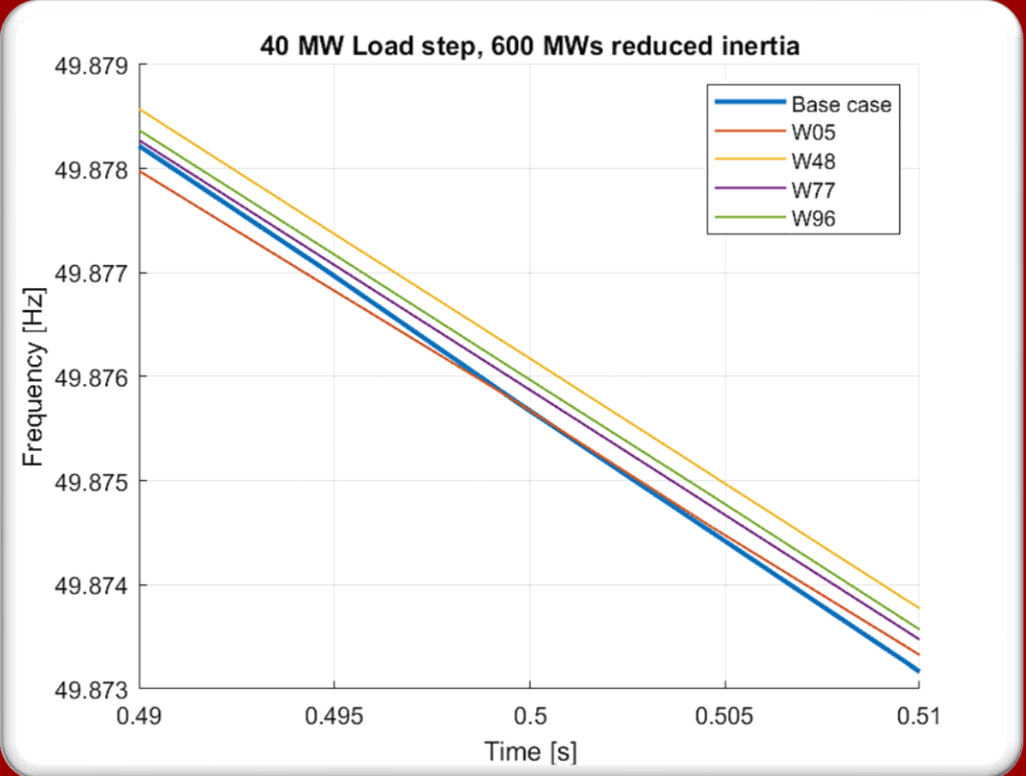
Methodology – Radial Grid Diagram



Methodology – RoCoF measurement

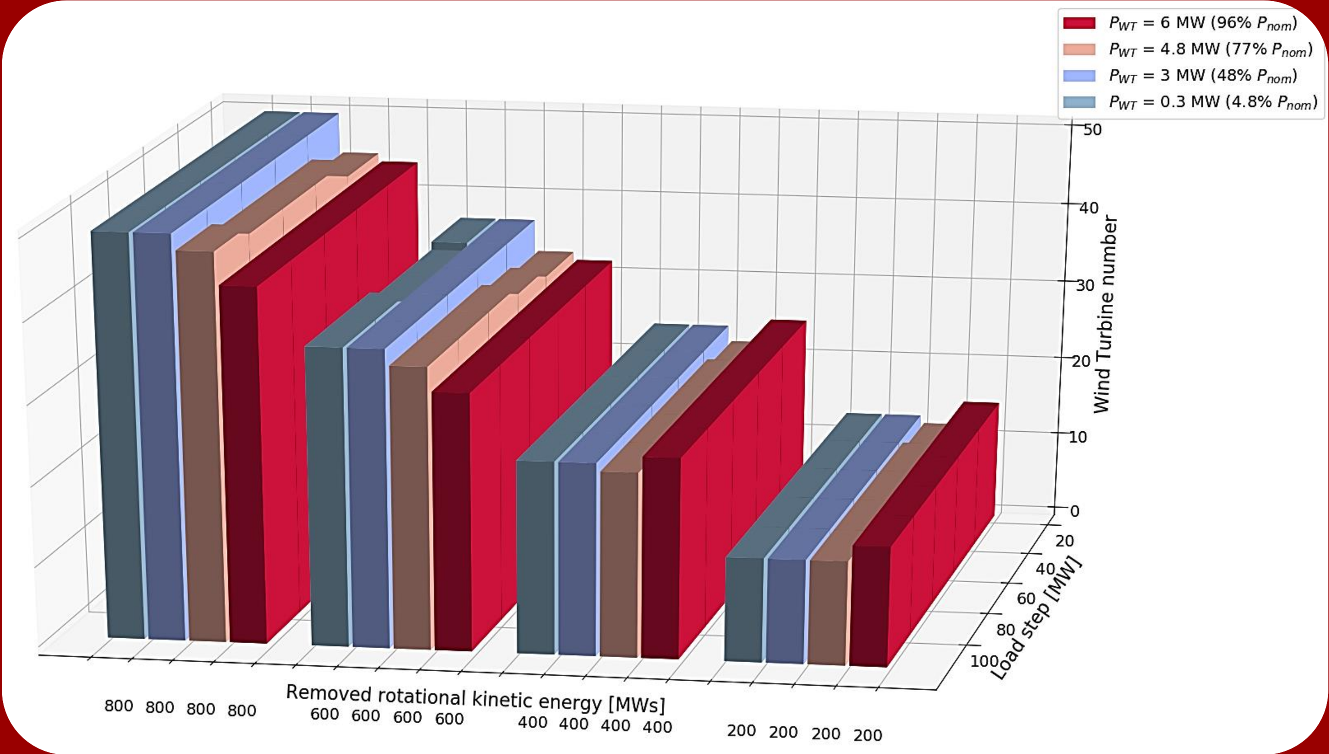


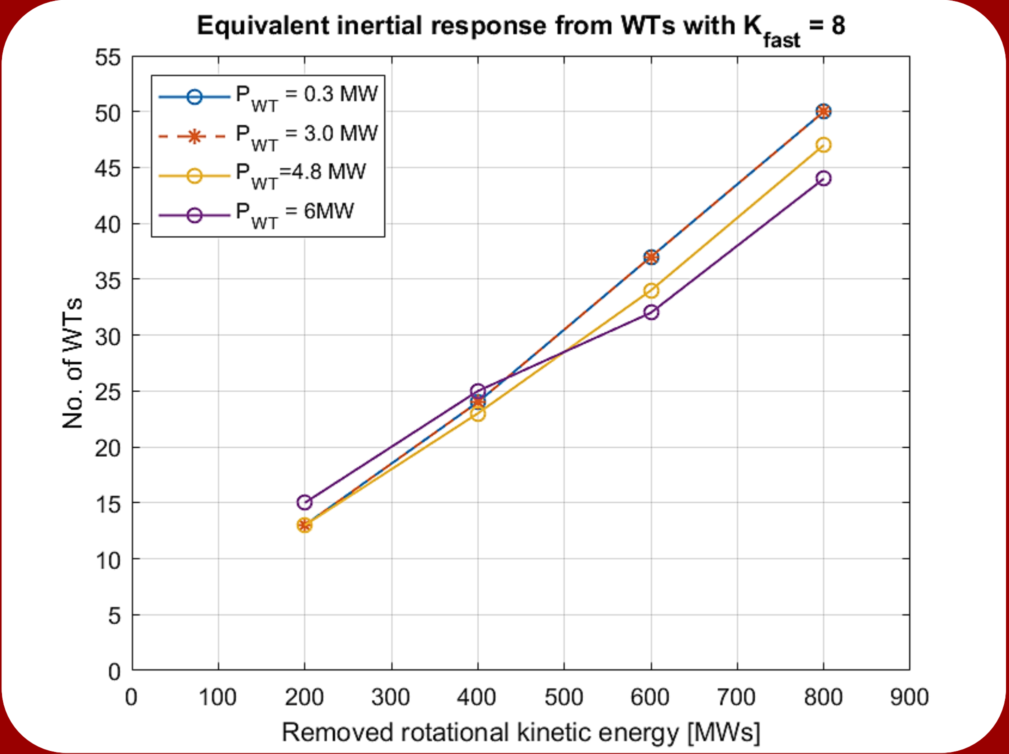
H = 6



- RoCoF measurements are done by finding the average RoCoF during the first 500 ms following the load step disturbance (at time 0).
- Using only one time point gives some uncertainty in the number of required WTs, since the WT support curves intersect the base case at different time-points (the number of WTs used in the right figure is [W05: 36, W48: 37, W77: 34, W96: 36]).

Results –Radial Grid

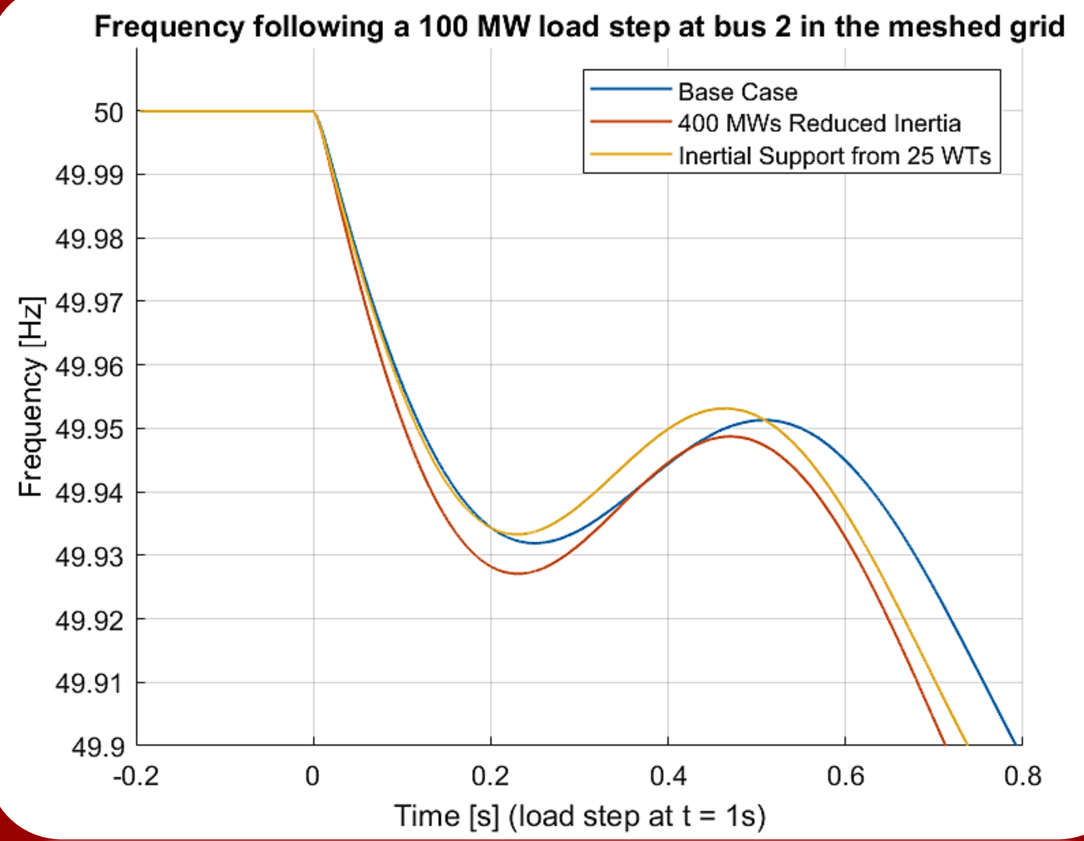


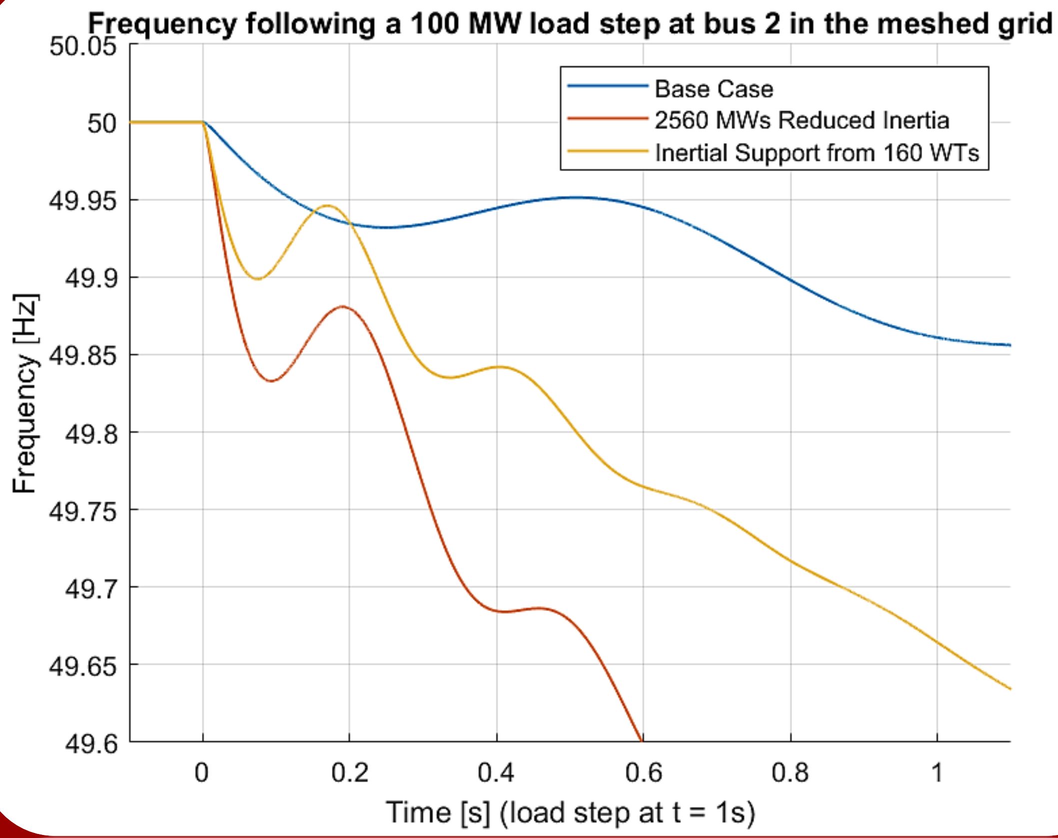


- The inertial response is nearly independent of the load step. In this aspect, synthetic inertia behaves just like rotating inertia.
- The equivalent inertia from wind turbines is approximately a linear function. Based on the radial grid data, 1 WT with $K_{fast} = 8$ corresponds to about 16 MWs of rotational inertia.

[MJ] rotational energy

Results – Meshed Grid Comparison





- Support from 25 WTs equivalent to 400 MWs inertia reductions, however support from 160 WTs is not enough to compensate for 2560 MWs reductions. This could indicate non-linear behavior.
- Synthetic inertia does not influence frequency oscillation periods. Frequency oscillations make RoCoF measurements complicated in meshed systems.

Discussion

- $K_{fast} = 8$ is the maximum gain in order to avoid underspeed/overloading protection system operation (when governors are included).
- Possible Enhanced Solution: Implement control system to vary the K_{fast} according wind speed – generator speed.
- Dead-band of the inertial controller should be implemented for more realistic results.
- Different number of WTs have been obtained in different wind speeds, due to MPPT operation.

Conclusions

- Equipping wind turbines with a synthetic inertia controller (SIC) can support system RoCoF in case of transient disturbances.

- The equivalent inertia available from WTs with a SIC is independent of load step, and almost independent of wind speed. This means that synthetic inertia behaves similarly to rotational inertia (for short time periods).

- $K_{fast} = 8$ is the maximum gain which ensures that the WTs does not disconnect at low wind speeds due to underspeed protection (when governors are included).

- With $K_{fast} = 8$, it was found that one wind turbine was equivalent to approximately 16 MWs of rotating inertia. This finding was tested in the meshed grid and the results showed decent correspondence for low levels of removed inertia.