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Electrical infrastructure and system integration: Advanced ancillary services from wind farms

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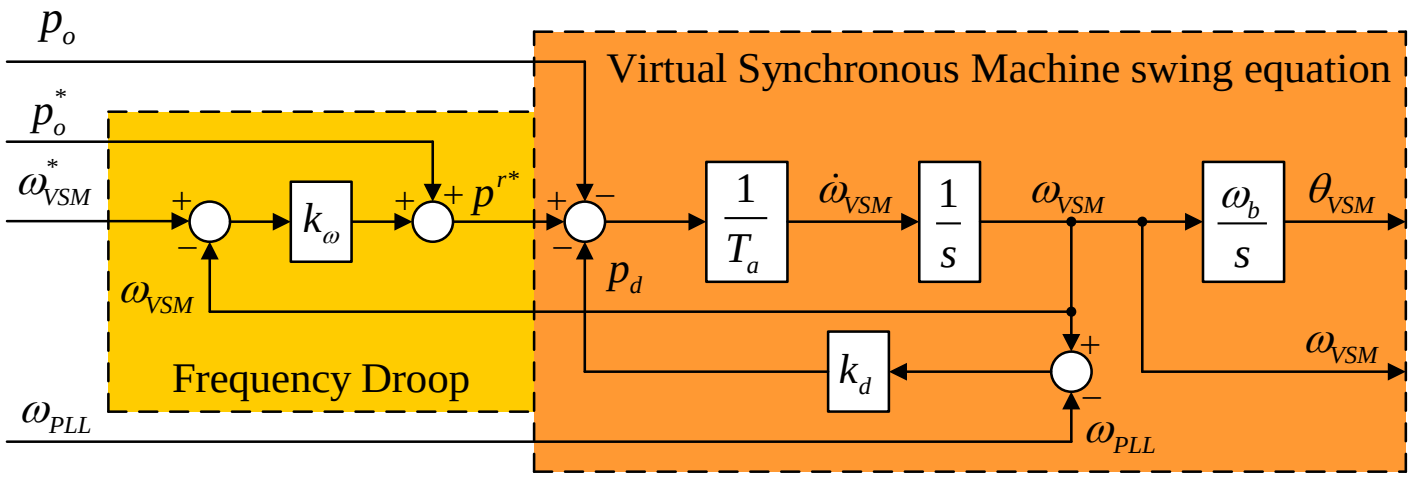
Ancillary services in wind farms

- Ancillary services are supporting services required by the power system operators to maintain correct functionality of the power system.
- Future power systems with higher share of renewables will be characterized by lower inertia and potentially weaker frequency regulation.
- Provision of ancillary services from large wind farms will be even more crucial.
  - Frequency support with synthetic inertia.
  - Grid forming capabilities (lower or no dependency on external grid).

Virtual Synchronous Machine

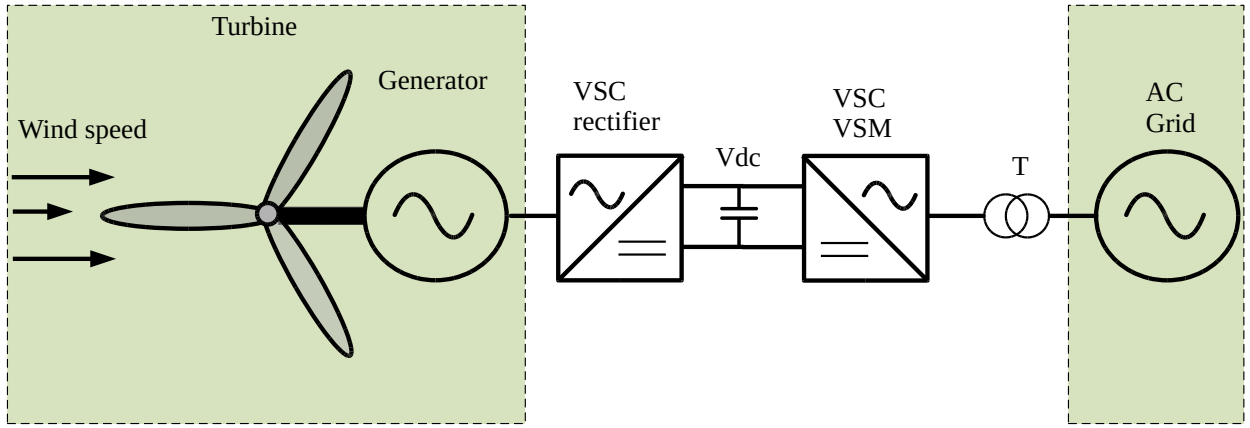
- Common implementation scheme to provide grid forming capabilities and synthetic inertia.

- Controlling Power Electronic converters to emulate the behavioural characteristics of synchronous machines
  - Inertial dynamics in the form of a virtual swing equation.



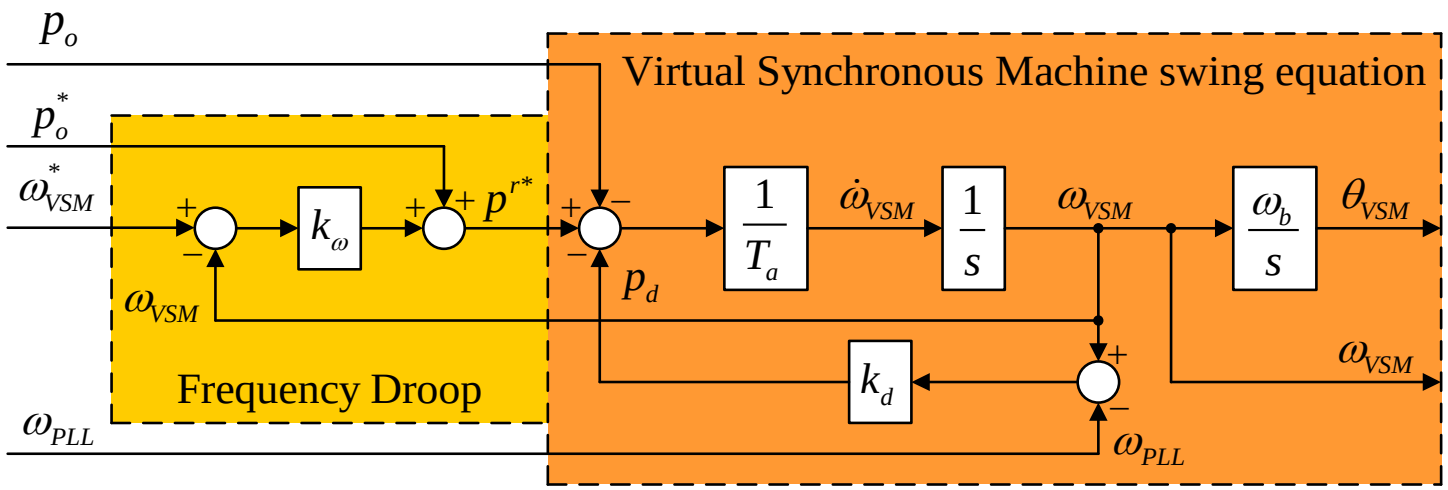
VSM in a wind turbine

- Normally the turbine side converter is controlling the power and the grid side the dc bus voltage.
- Roles are inverted and the grid side is controlled as a VSM while the turbine side controls the dc voltage.
  - The VSM controls the power based on MPPT but can add virtual inertia reaction to disturbances.
  - Virtual inertia energy extracted from wind turbine rotating inertia.



Dynamic limitations of VSM schemes

- VSM can have a slow reaction speed to power production variations.
- The power from the VSM is linked to the virtual rotor position.
  - Changes in the grid voltage phase angle or in the virtual rotor angle are reflected directly in the power flow.
- The active power reference is inversely scaled with the virtual inertia value and passed through two integrators.
  - The integrators reduce the speed of the dynamic response.
  - Large values of inertia further reduce the bandwidth.



Improving the Power Reference Tracking

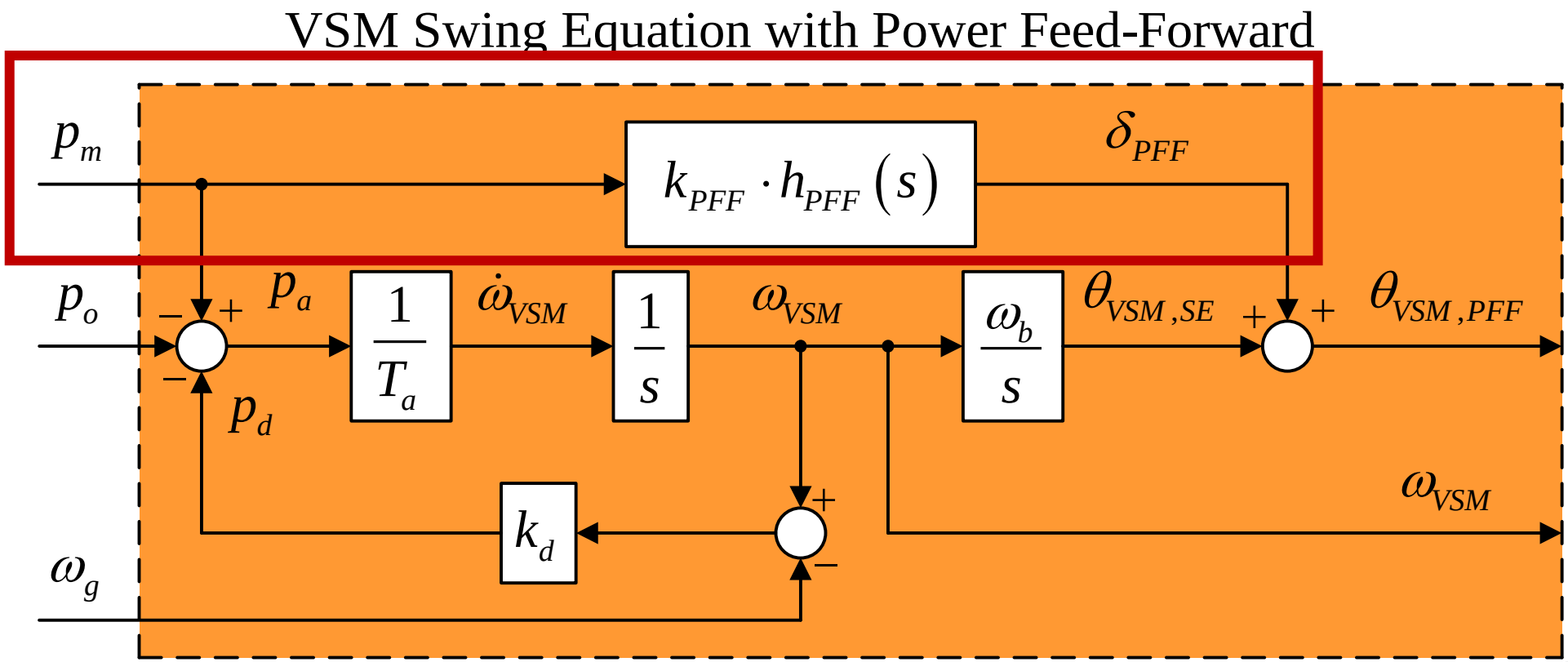
- Power reference tracking is critical for a wind turbine to avoid need of oversizing the dc bus capacitor.

- Developed Power Feed-Forward (PFF) strategy scheme for improving tracking without affecting grid forming and inertia support.

S. D'Arco and J. A. Suul, "Improving the Power Reference Tracking of Virtual Synchronous Machines by Feed-Forward Control," *2021 IEEE 19th International Power Electronics and Motion Control Conference (PEMC)*, 2021, pp. 102-107, doi: 10.1109/PEMC48073.2021.9432548.

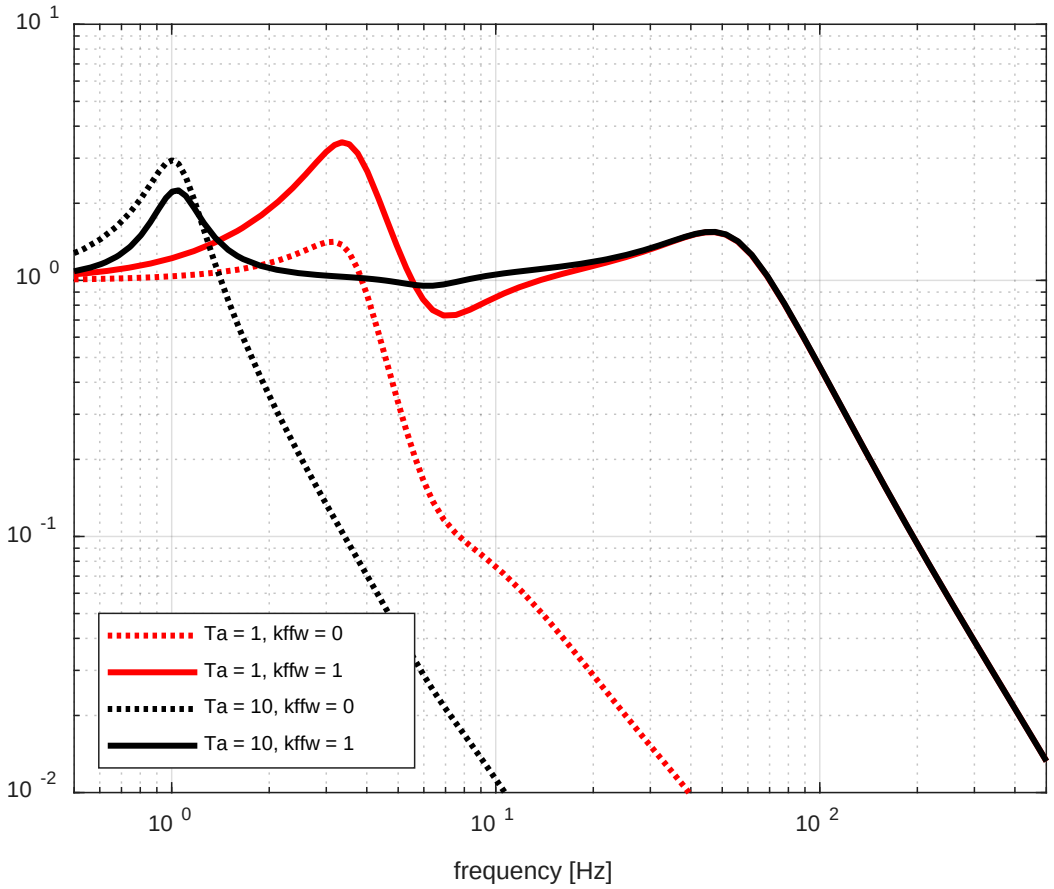
NORTH WIND

Power Feed-Forward (PFF) Strategy



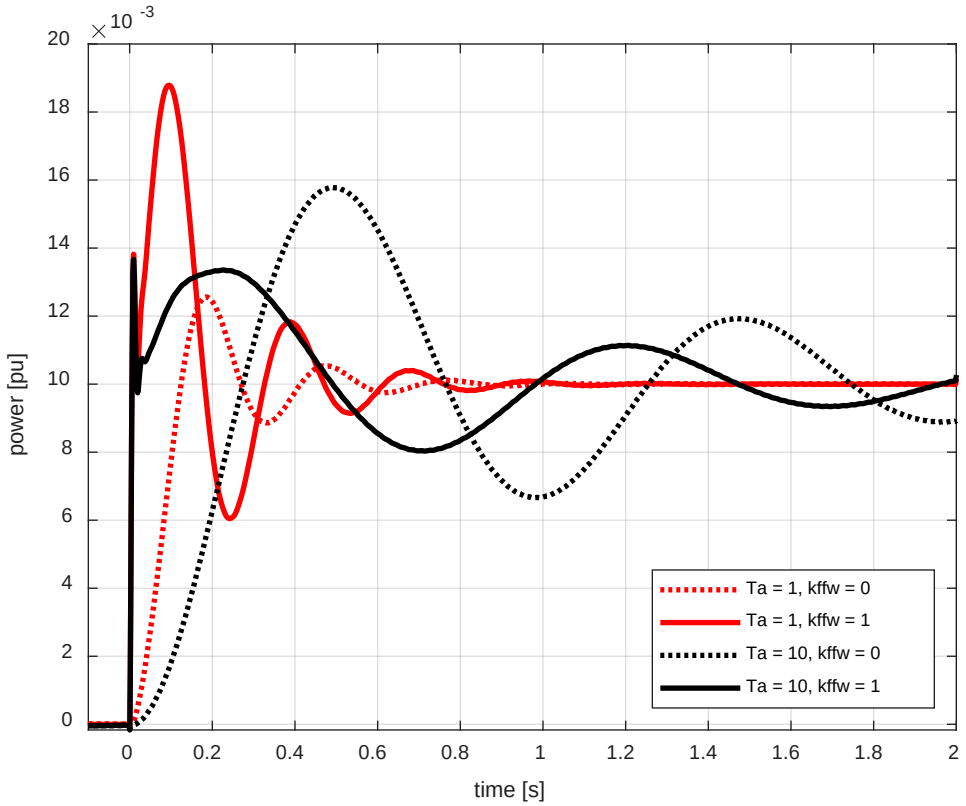
Transfer function: Power reference to Power

- The PFF clearly increases the speed (bandwidth) of the VSM for tracking the power reference.
- Inertia acts as a low pass filter for the power reference.
  - Increase value of inertia leads to a slower response to changes in the power reference for the swing equation.

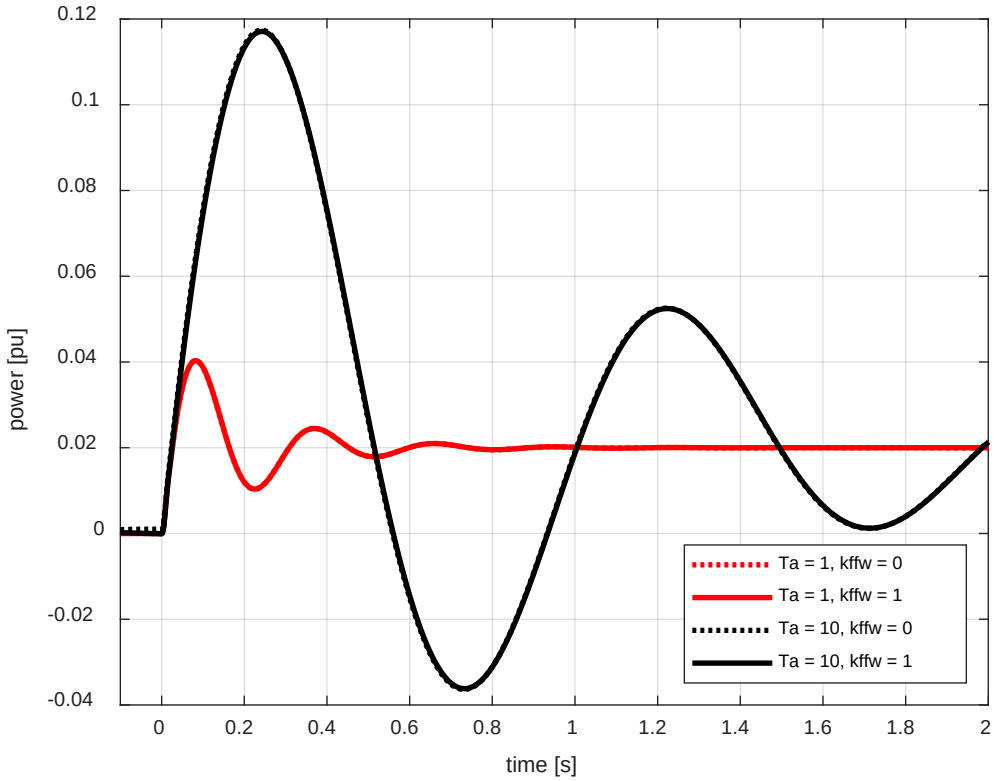


$h_{p^*,p}(s) = p_o(s)/p_o^*(s)$

Time-domain analysis



Response to a 1% step in the power reference



-2 10^{-3} pu step perturbation in the grid frequency

Further plans within Northwind

- Modify the feedforward to allow a more precise and faster correction.
  - Improve the steady state correction setpoint.
  - Aim at less overshoot and better dynamics for wide inertia range.
- Increase the TRL from 3 to 4
  - Validate the control scheme in the National Smartgrid Laboratory.

Conclusions

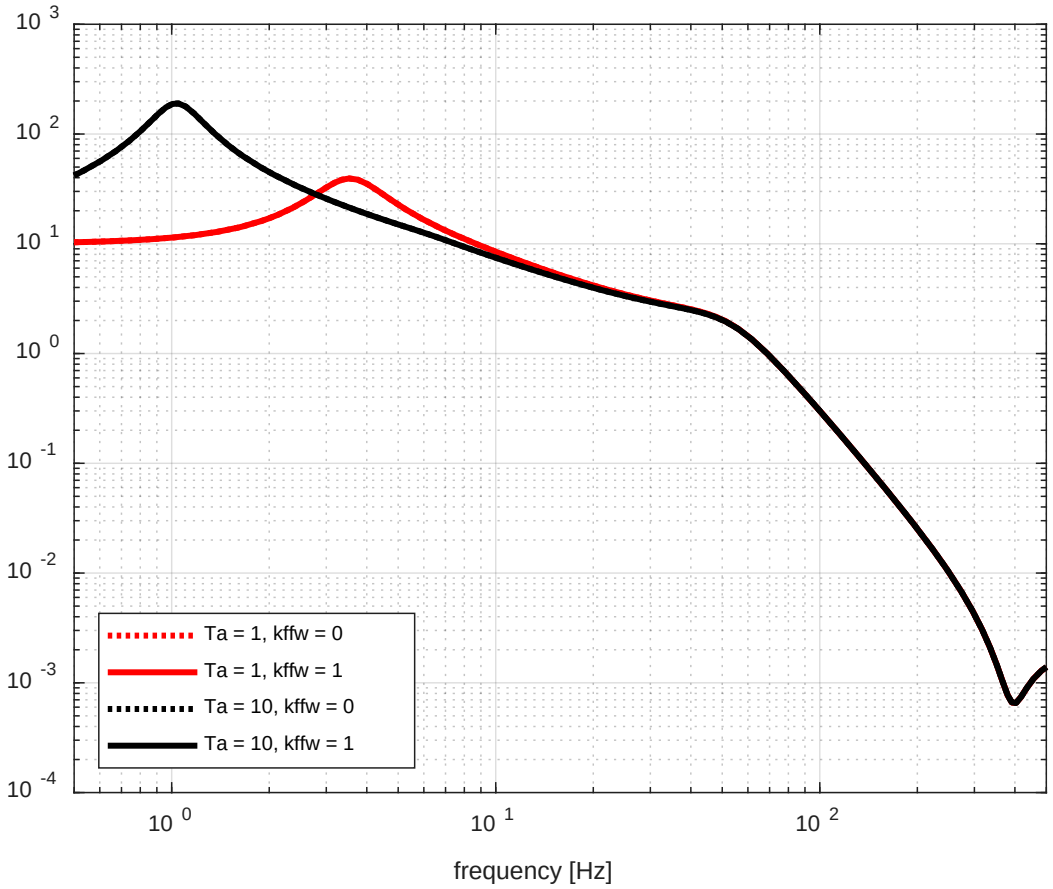
- Ancillary services will be even more critical in the future.
- A VSM can provide grid forming capabilities and virtual inertia in wind farms.
- The power reference tracking in a VSM based control is in general poorer compared to a classical grid following schemes.
  - The virtual inertia acts like a low-pass filter.
- Developed scheme with a power feedforward
  - Grid forming features and response to grid events can be preserved.
  - Power tracking bandwidth can be increased.
  - Aim to raise TRL from 3 to 4.

www.northwindresearch.no

Transfer function: Grid frequency to Power

- The Bode plots for the scheme with and without PFF are overlapping confirming that the feedforward does not affect the characteristics of the VSM scheme for disturbances in the grid frequency.

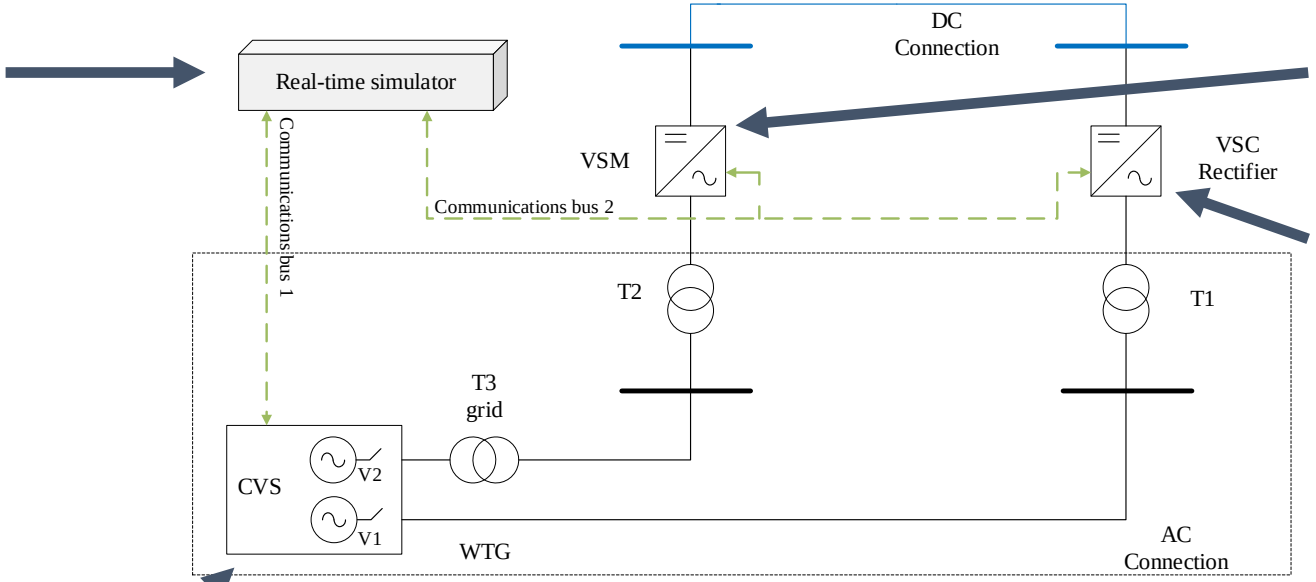
- The feedforward has no effect on the power synchronization mechanism and the grid forming capabilities.



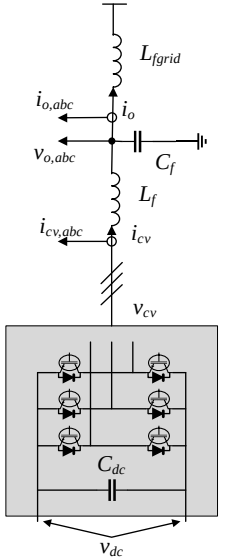
$h_{\omega g,p}(s) = p_o(s)/\omega_g(s)$

Implementation and experimental validation

Real time simulator



Power converters



Grid emulator