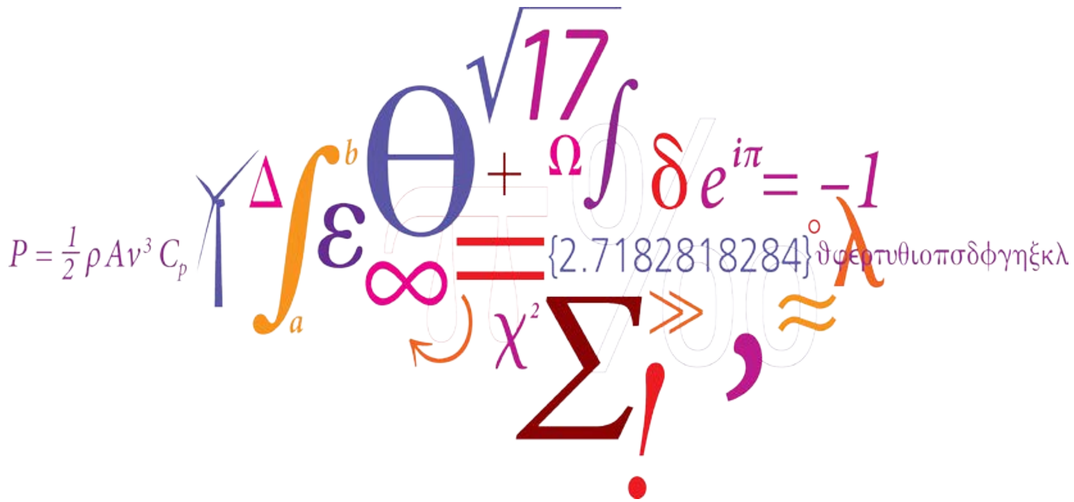
18th Wind Integration Workshop
Dublin Ireland
16 - 18 October 2019

DTU

Power Angle Small Signal Stability Analysis of Grid-Forming Inverter with VSM Control

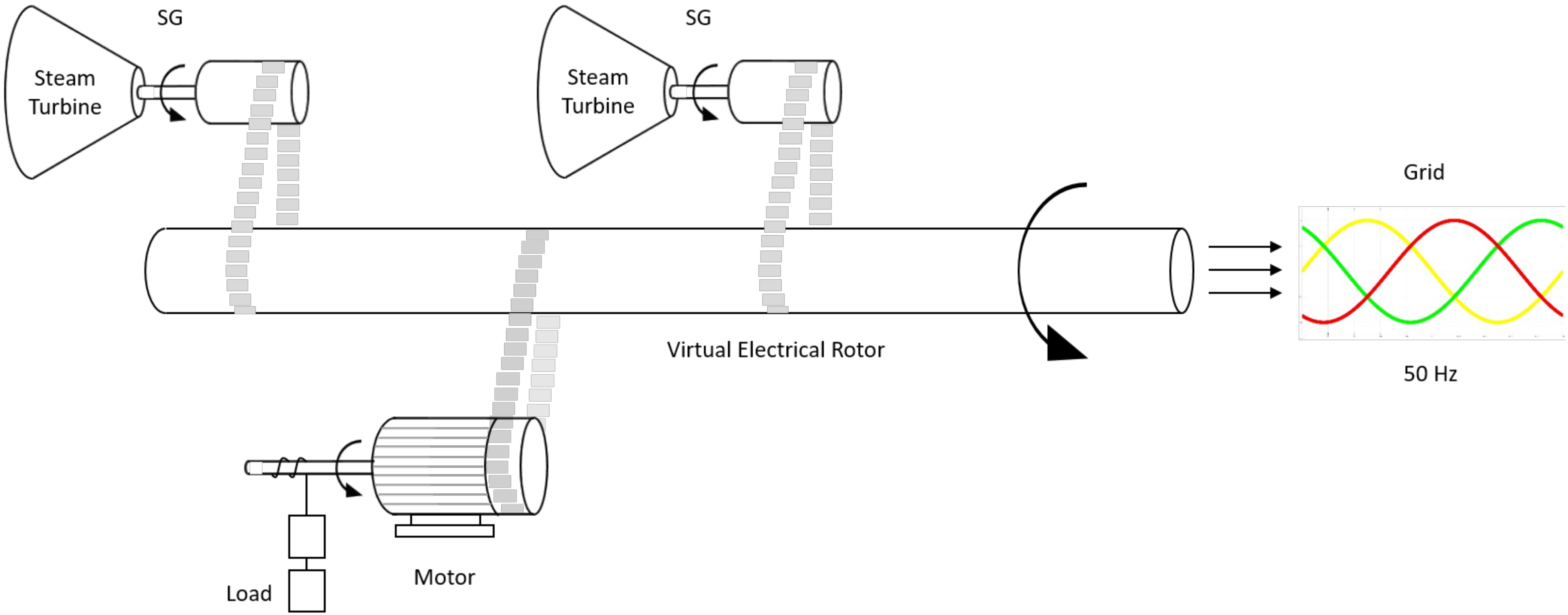
Liang Lu
PhD student

Dublin, Ireland
18-10-2019

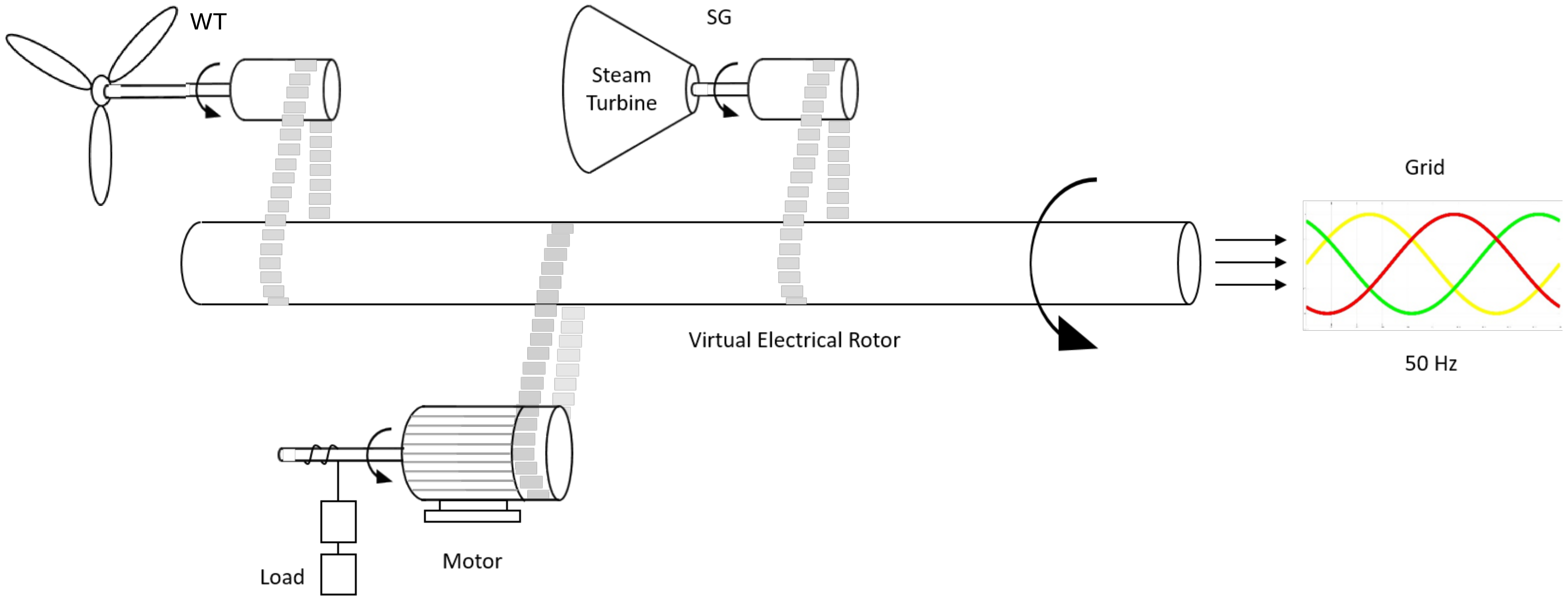


DTU Wind Energy
Department of Wind Energy

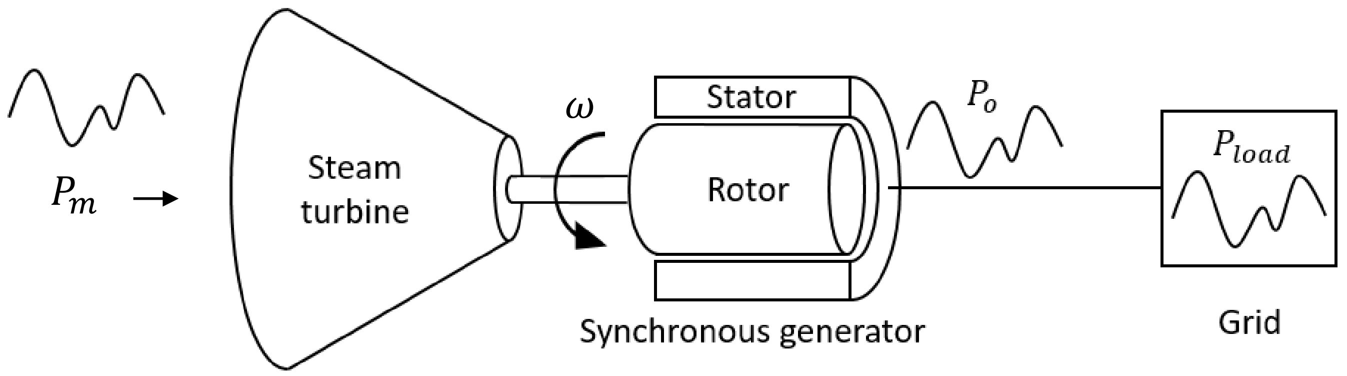
Power System Frequency Stability



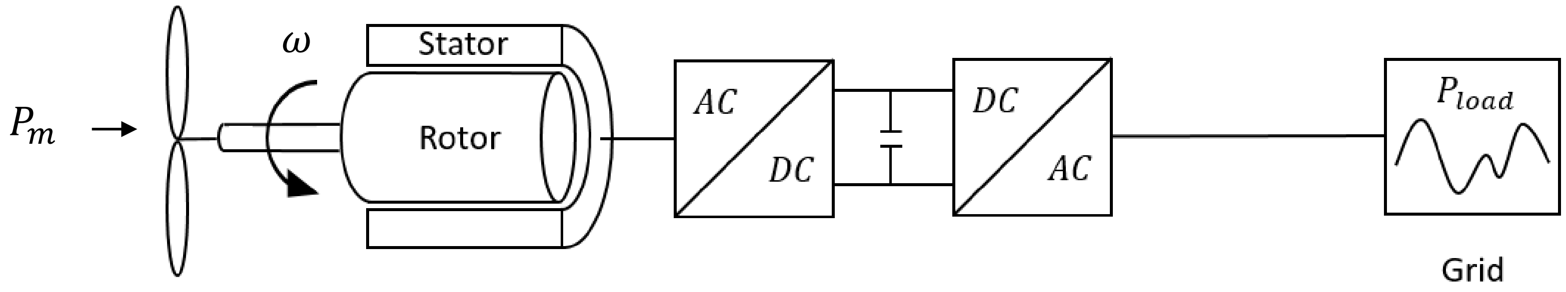
Power System Frequency Stability



Power System Frequency Stability



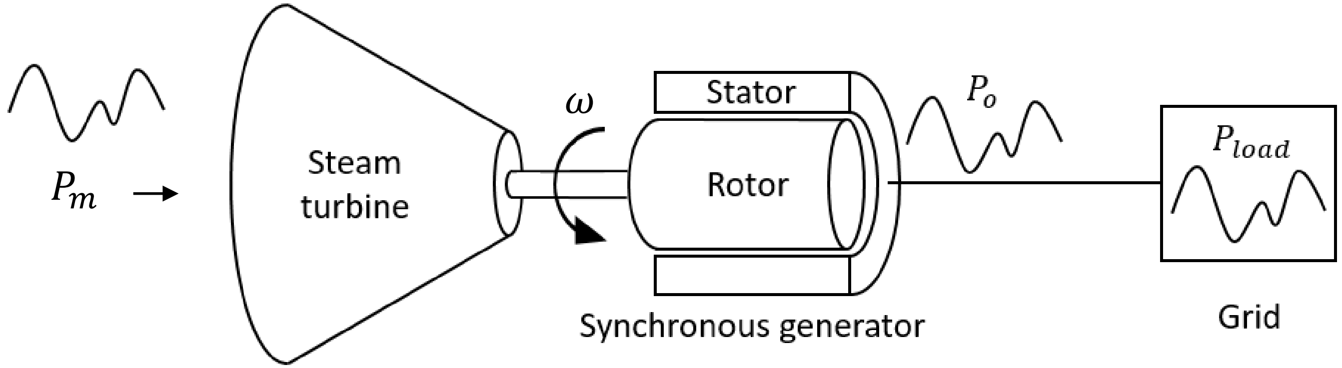
$$P_m - P_o = J\omega \frac{d\omega}{dt}$$



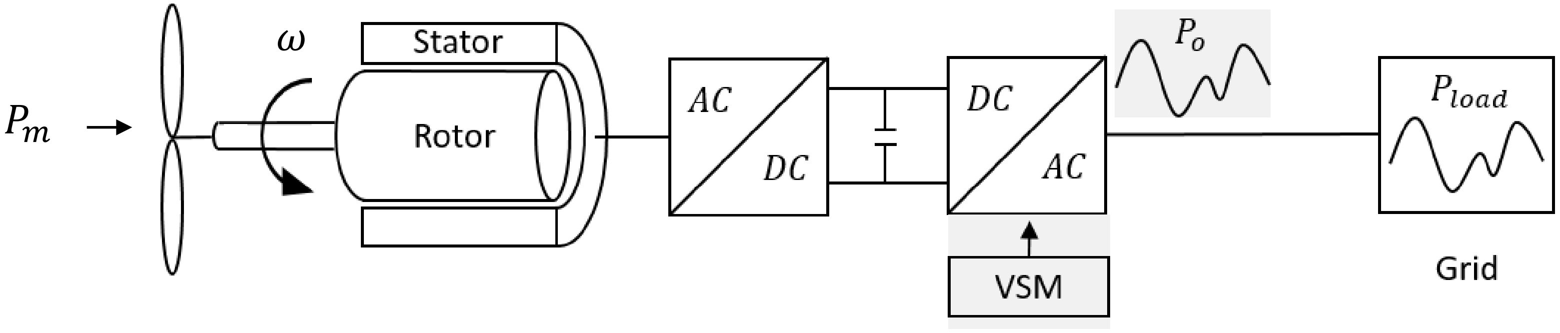
Type-4 wind turbine

Virtual Synchronous Machine (VSM) Control

- A control scheme for a converter to enable renewable power sources to behave as a synchronous machine (SM) by adding the model and control of an SM within the control scheme;



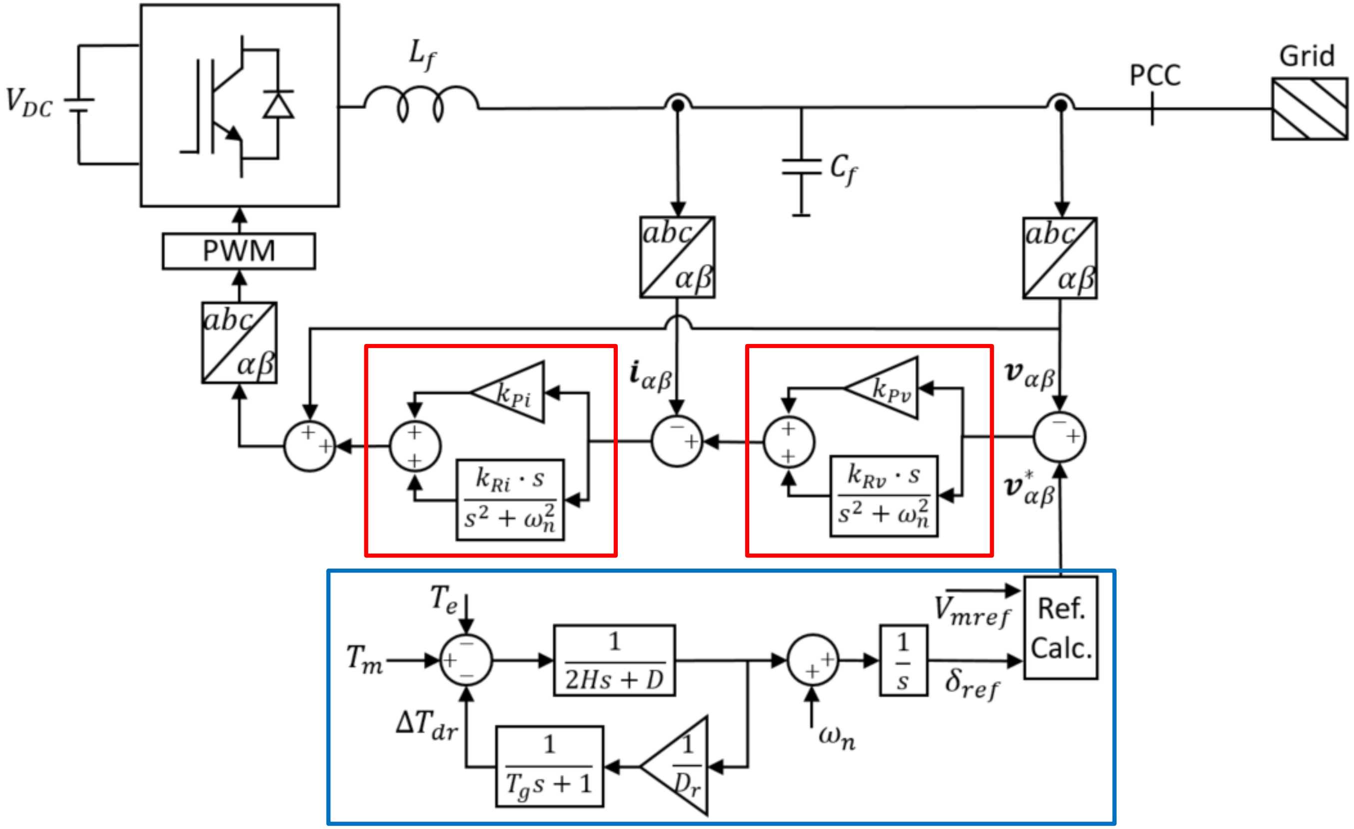
$$P_m - P_o = J\omega \frac{d\omega}{dt}$$



Type-4 wind turbine

Motivation

A VSM Control Scheme for WTs



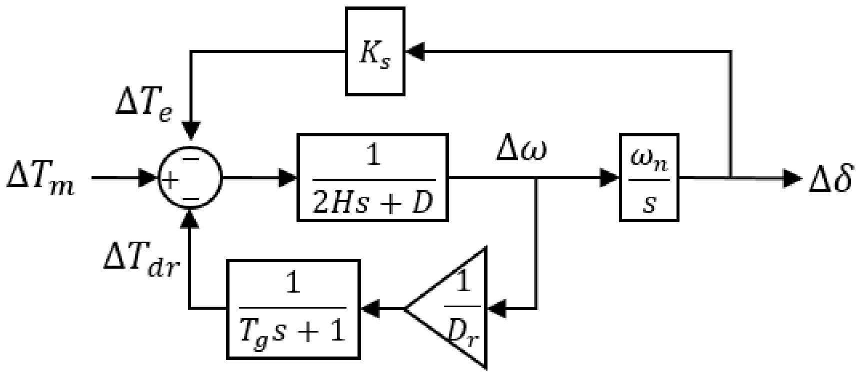
Power Angle Small Signal Stability

- Focusing on the power loop while idealizing inner voltage and current loops;
- State space representation and block diagram of an inverter connected to an infinite bus;
- Influence of parameters on the stability by analyzing eigenvalue trajectories;

https://orbit.dtu.dk/en/activities/a-virtual-synchronous-machine-control-scheme-for-wind-turbines(4cdc26fd-1829-4c00-af62-5775529c73f3).html

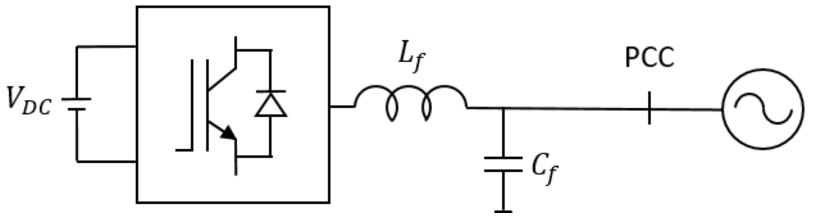
Power Angle Small Signal Stability (PAS) Model

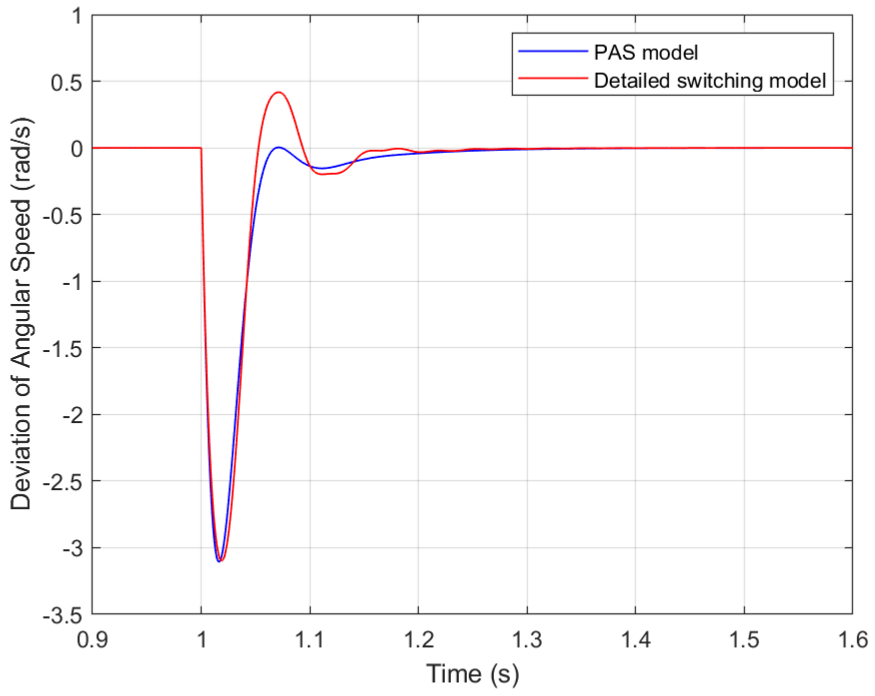
$$\frac{d}{dt}\begin{bmatrix}\Delta\omega\\ \Delta\delta\\ \Delta T_{dr}\end{bmatrix}=\begin{bmatrix}-\frac{D}{2H} & -\frac{K_s}{2H} & -\frac{1}{2H}\\ \omega_n & 0 & 0\\ \frac{1}{T_g D_r} & 0 & -\frac{1}{T_g}\end{bmatrix}\begin{bmatrix}\Delta\omega\\ \Delta\delta\\ \Delta T_{dr}\end{bmatrix}+\begin{bmatrix}\frac{1}{2H}\\ 0\\ 0\end{bmatrix}\Delta T_m$$



$$K_s=\frac{E'E_b}{X}\cos\delta_0$$

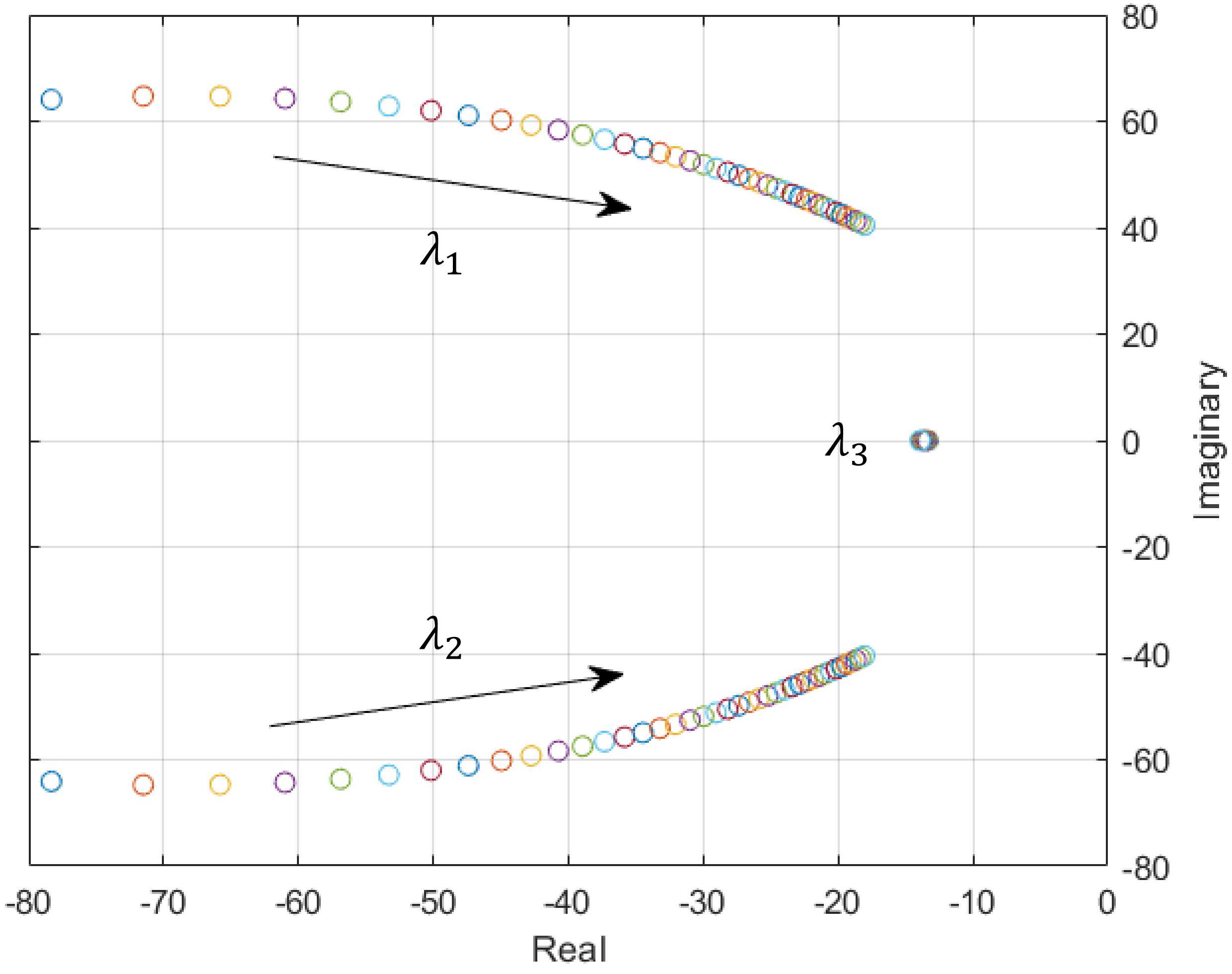
Verification





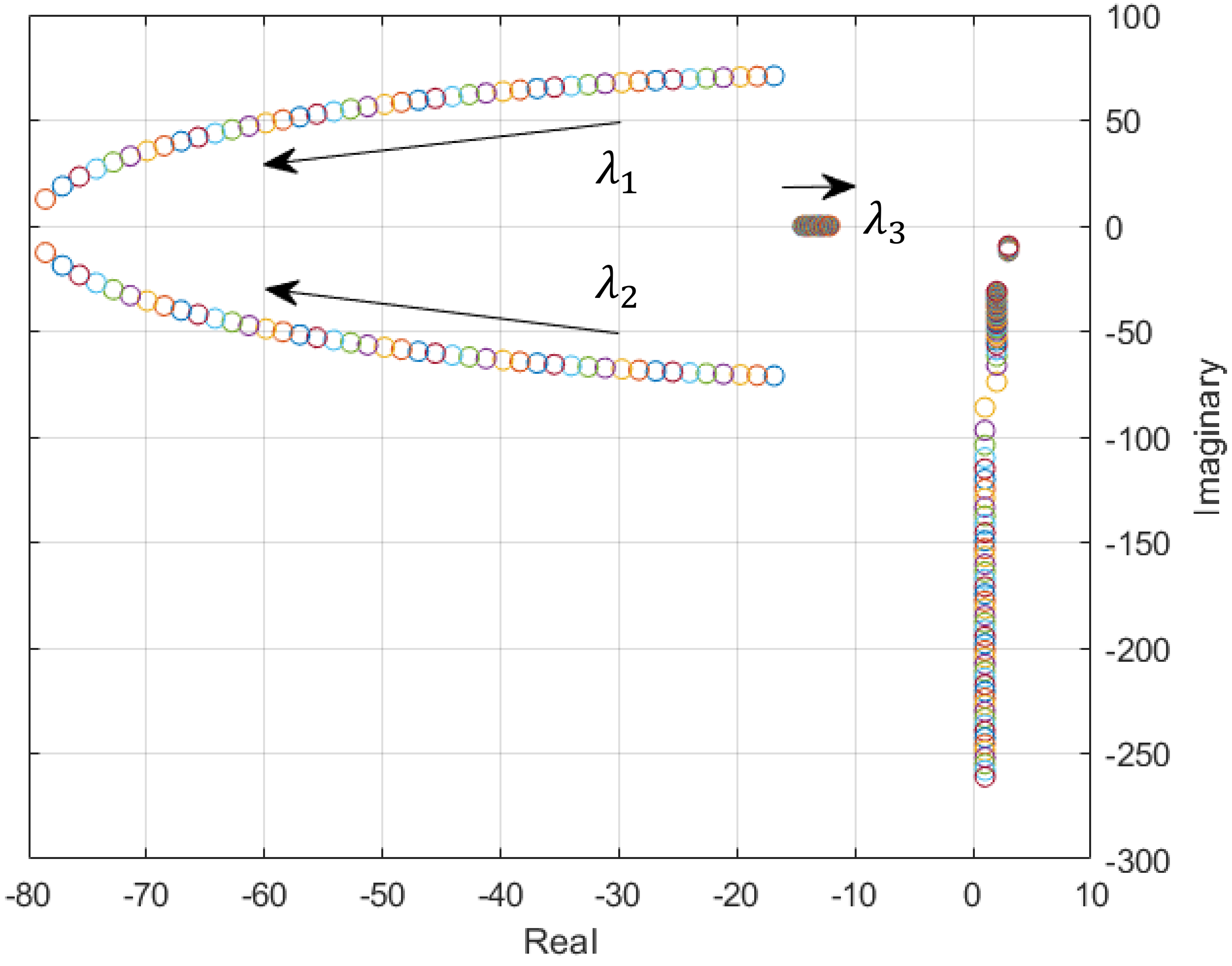
- $t = 1s$, T_m is dropped by 0.5 pu, or P_m is dropped by 5 kw

Parameter Design -- *H*



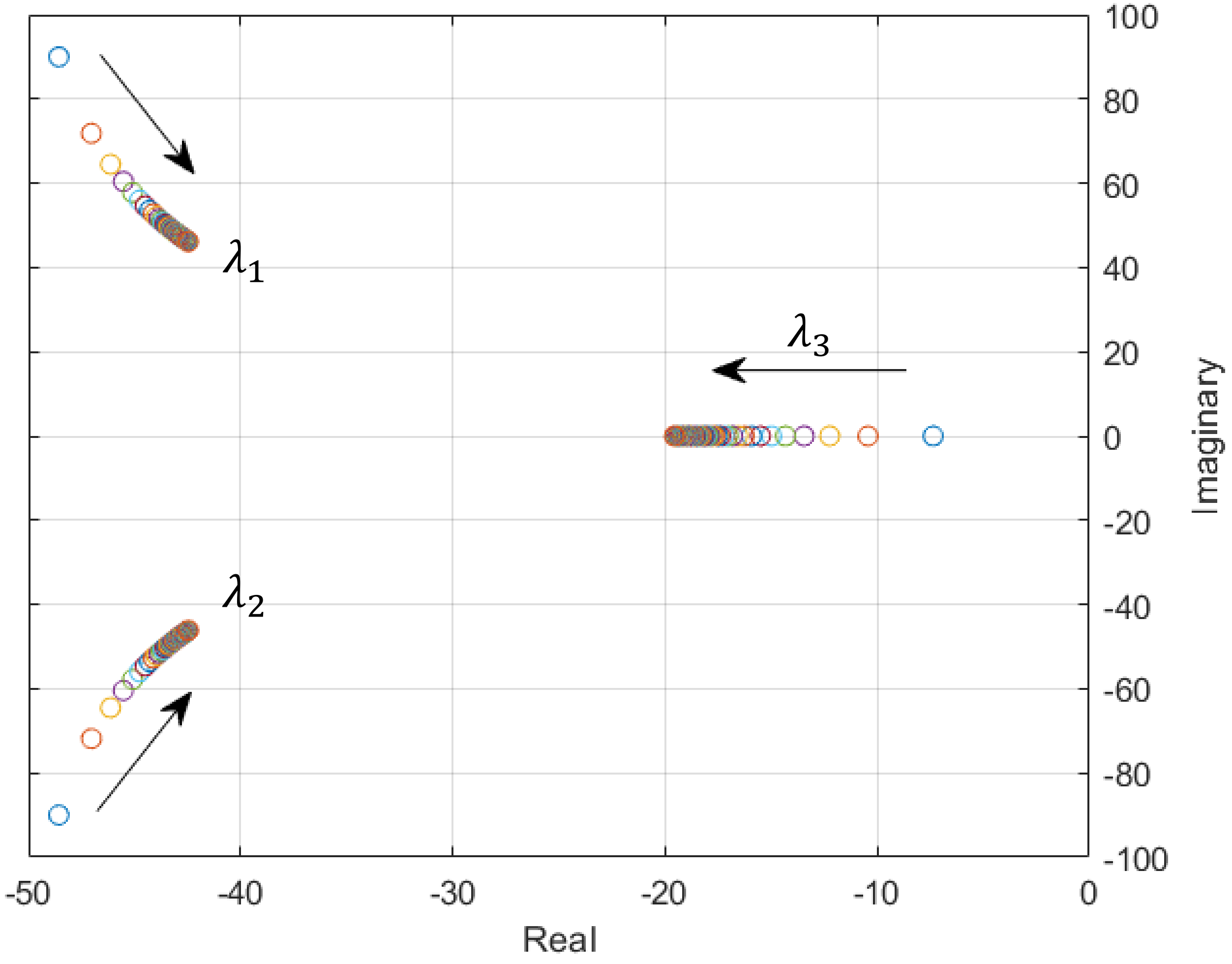
- 0.1 ~ 0.5;
- Little influence on λ_3;
- Stability margin reduced by increasing H;
- A larger H is better for inertia response;
- A compromise;
- Exact value also depends on grid code requirements and converter rating;

Parameter Design -- D



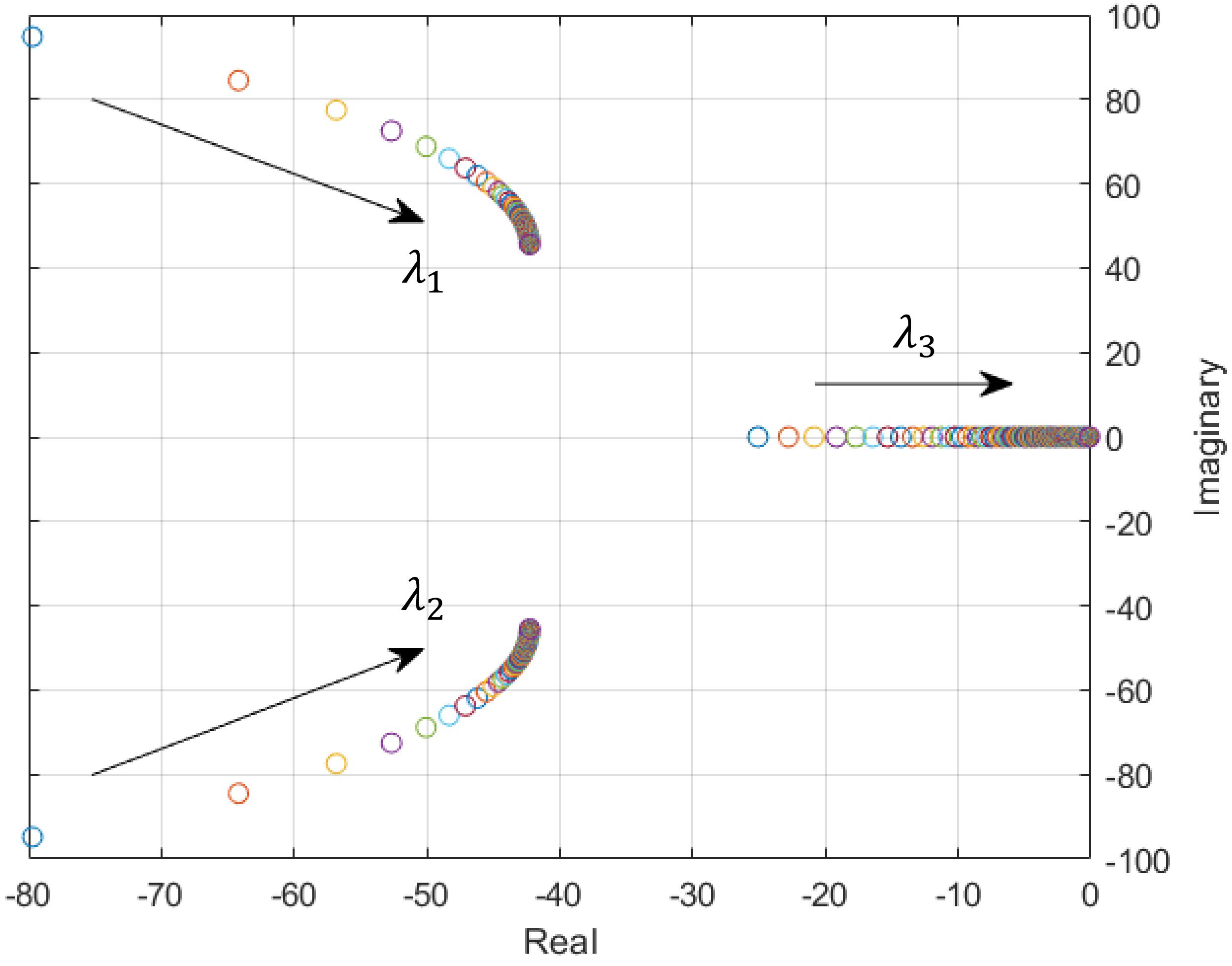
- 10~53: stable, 54~100: unstable;
- Little influence on λ_3;
- Stability margin improved by increasing D in the stable range;
- Positive effects of a smaller D;
- A trade-off;

Parameter Design -- D_r



- 1% ~ 100%;
- Much influence on λ_3;
- Stability improved by increasing D_r;
- Constraint and most likely determined by grid code requirements, converter rating and capacity of energy storage;

Parameter Design -- T_g



- 0.01 ~ 10;
- Much influence on λ_3;
- Stability is worse when increasing T_g;

Conclusions & Future Work

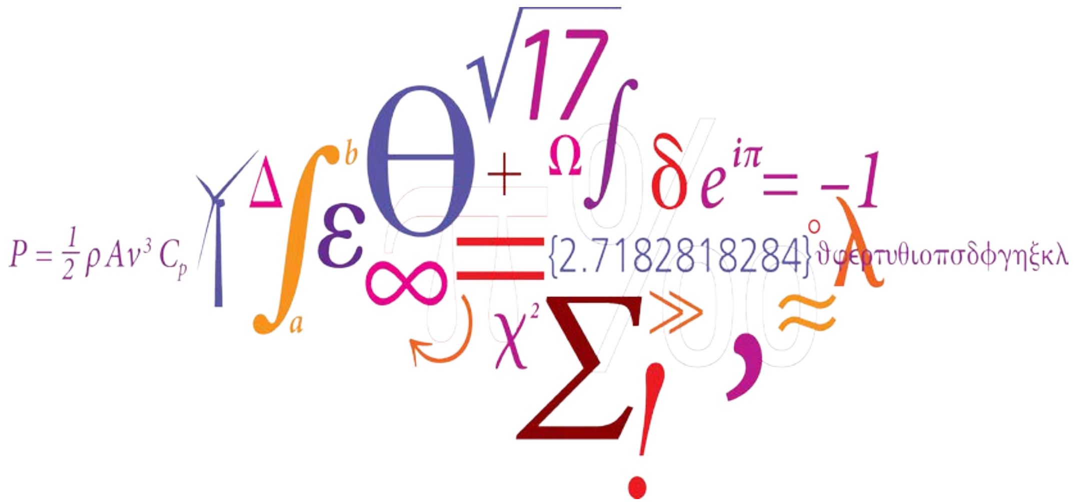
- Power angle small signal stability (PAS) is proposed as a simpler way of analyzing the small signal stability of VSM-controlled grid-forming inverters;
- Helpful for analyzing the rotor angle small signal stability of a big power system with large share of converter-interfaced renewable power sources;
- A larger inertia constant H or damping coefficient D reduces the stability margin, but enhances the inertial response and frequency control capability;
- A larger droop D_r or a smaller response time T_g helps improving the stability;

❑ Overall and systematic design of all parameters simultaneously considering practical constraints;

❑ What is the optimal or acceptable power response from a non-synchronous power source for fast frequency regulation?

Thank you !

Liang Lu
lilu@dtu.dk



DTU Wind Energy
Department of Wind Energy

TotalControl

This work has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 727680 (TotalControl).

This work has also received funding from project PowerKey (EUDP Project No. 12558).