A Fundamental Study of Applying Wind Turbines for Power System Frequency Control

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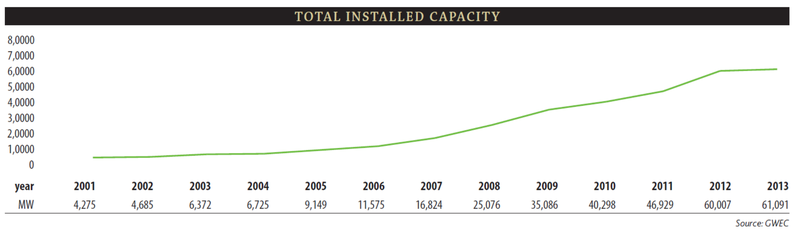
Introduction

- Wind generation is increasing rapidly in power systems through the world.
- Wind is clean, renewable, mature and economically ready to compete with conventional generation.
- WTG fundamentally different than conventional generation:
  - Power electronic interfaces decouples WT rotor inertia
  - WT prime mover (the wind) is not dispatchable

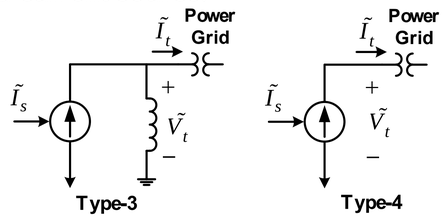


Total installed wind capacity in the US

WTG models

WTGs of Type-3 (DFAG) and Type-4 (full-converter) and Type-4 WTG are the interest of this work because they are the most popular in new installation. These devices operate at a variable speed to maximize the wind energy capture.

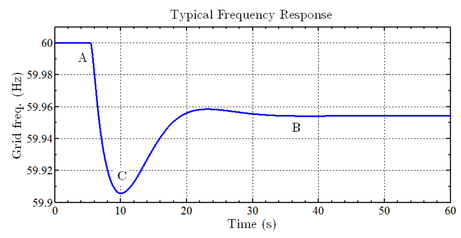
- For Type-3 power transfer occurs partially through power electronics (around 30% for Type-3).
- For Type-4 all the power transfer occurs through the power electronics interface.
- For both types the model as seen from the grid is a controlled current source.



- Power electronics allows for a separate control of active and reactive power.
- Modeled as a **PV** bus (generator type of bus) for **loadflow studies**.

Freq. Control Overview

(A) RoCoF
(B) Settling frequency
(C) Frequency nadir



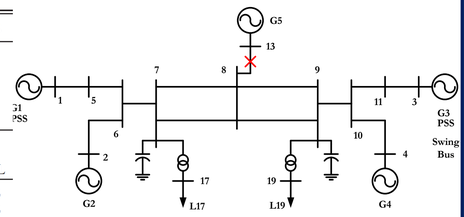
Test System

TEST SYSTEM GENERATOR AND LOAD DATA

	P (pu)	Q (pu)	TG	Exc. ST3	PSS
G1	6.738	1.913	✓	✓	✓
G2	6.738	2.607	✓	✓	
G3	6.738	1.187	✓	✓	✓
G4	6.738	0.889	✓	✓	
G5	1.05	0.3751	✓	✓	

LOAD DATA

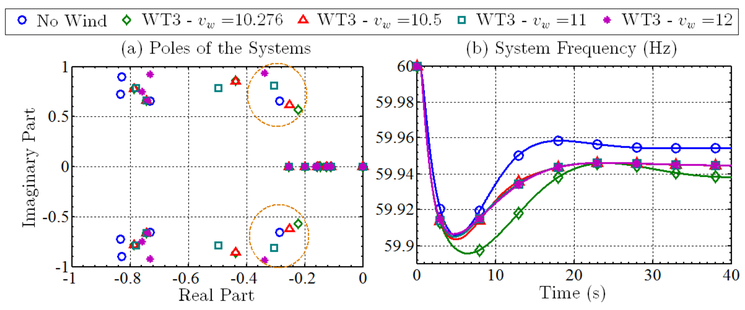
	P (pu)	Q (pu)	%CPL	%CCL	%CIL
L17	13.67	1	20%	35%	45%
L19	13.67	1	20%	35%	45%



- System described by 66 states
  - 6 states each machine using a sub-transient model (30 states)
  - TG and Excitation System 3 states each (30 states)
  - PSS in Generators 1 and 3, 3 states each (6 states)

Integrating Wind

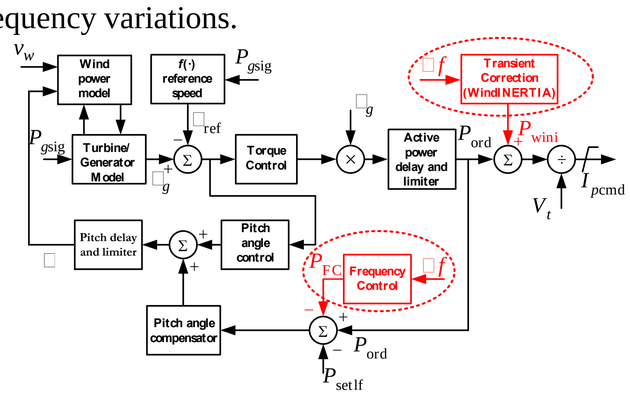
- Type-3 WTG integrated into the system replacing completely Generator at Bus4.
- System consist of 71 states (17 of which correspond to the WTG)
- Same loss of generation event was simulated for different wind speeds.



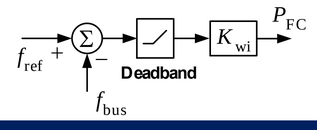
- As wind is integrated the frequency response of the system is deteriorated.
- Need for wind to provide frequency response capabilities.

Proposing a frequency response controller for WTGs

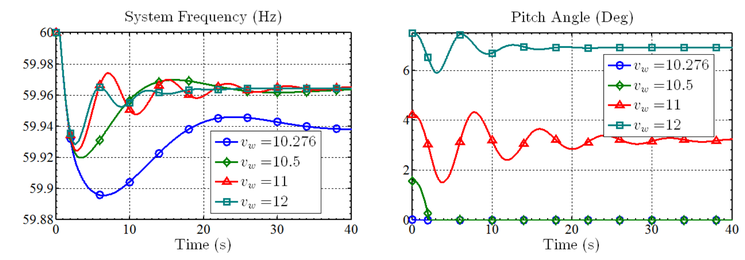
- Intentionally pitch the blades to spill power and create a headroom. This means increasing the pitch angle from zero to $q_{lf} = f_q(P_g, H_r, v_w) > 0$
- Calculate a pitch angle depending on the desired headroom and the wind speed.
- **Governing control:** make pitch angle control responsive to frequency variations.



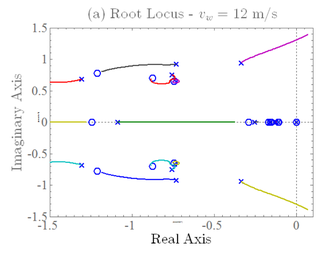
- Natural approach: proportional control



- Validation in the test system at 25% wind penetration for different wind speeds



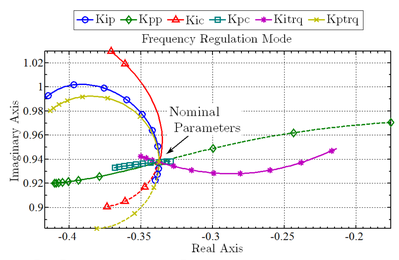
- From small signal analysis it can be seen that the proposed control loop interacts and destabilizes the *frequency regulation mode*.



Parameter adjusting

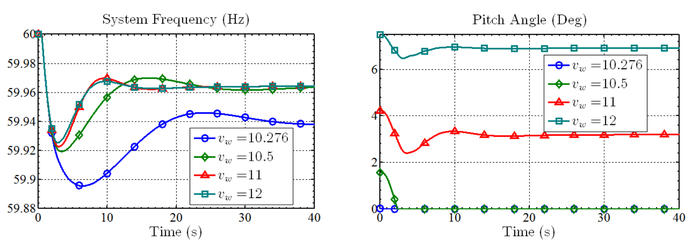
How to solve the oscillation in a simple manner?

- Perform a sensitivity analysis on the control parameters of the WTG

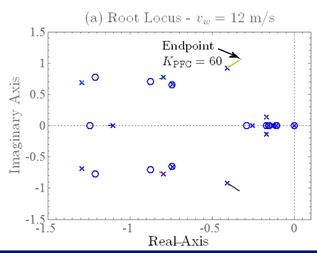


Note that **Kpp** is the constant that has the most effect on the mode

- Validation in the test system with 25% wind

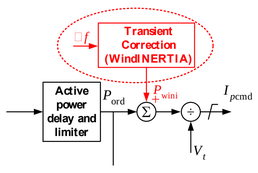


- Small signal analysis shows that the frequency regulation mode is less sensitive to the proportional frequency feedback

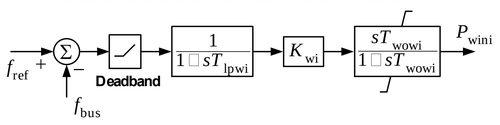


Parameter adjusting

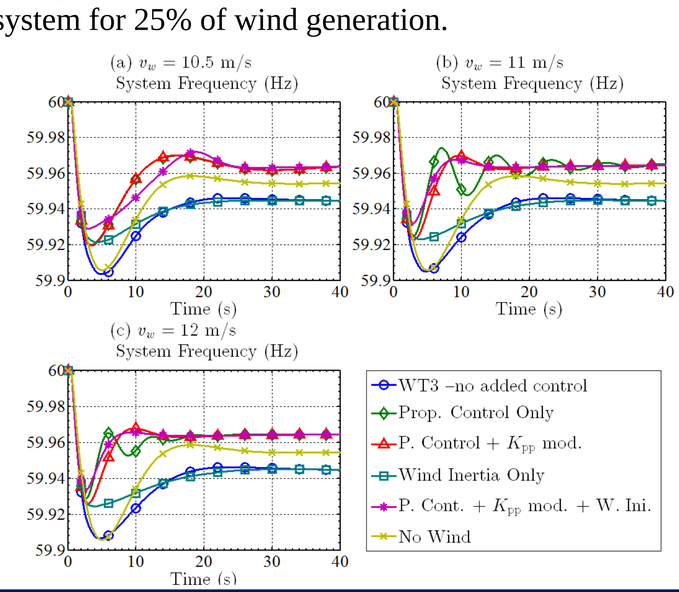
- To further improve RoCoF and frequency nadir a transient frequency controller is added.



- Transient controller structure

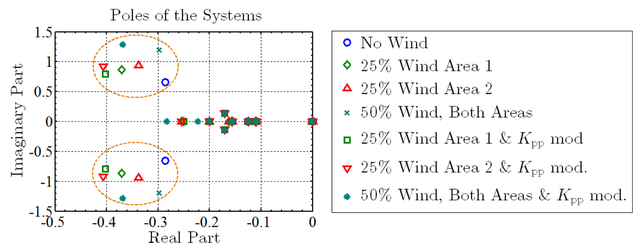


- Comparison of different control approaches in the test system for 25% of wind generation.

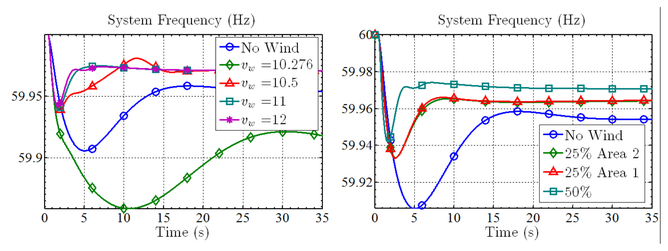


50% Wind Penetration

- Parameter adjusting at 50% Wind



- Validation in the test system with 50% wind



Conclusions

Results indicate that including proper frequency regulation controls in wind generation improves considerably the frequency response of the system. This is due to the fact that wind generation interfaces with the grid through power electronics, allowing a faster and more flexible control of the power output.

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