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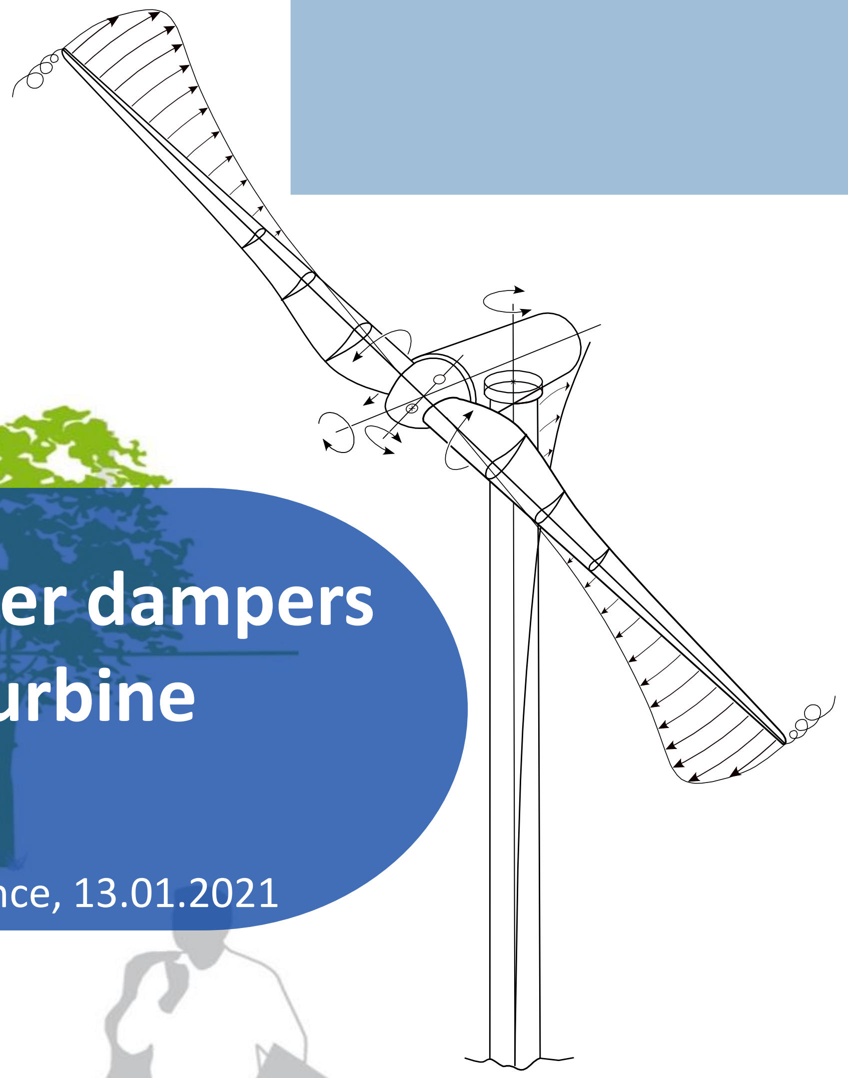


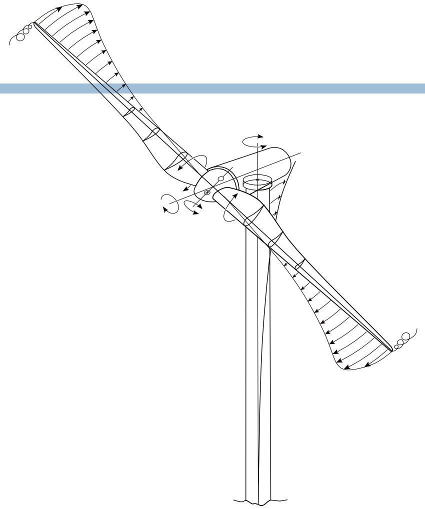
The effect of a speed exclusion zone and active tower dampers on an upwind fixed-hub two-bladed 20 MW wind turbine

F. Anstock[1], M. Schütt[1] and V. Schorbach[1]

[1]Hamburg University of Applied Sciences

Deep Wind Conference, 13.01.2021

Who are we?



Cooperation project:

“X-Rotor – two-bladed wind turbines”

20 MW turbines of the next generation

Between HAW HAMBURG | CC4E

and SIEMENS Gamesa RENEWABLE ENERGY

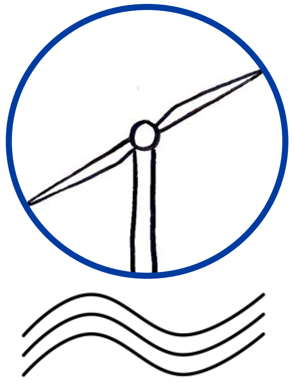
Funded by Federal Ministry of Education and Research

Source: Levin Schilling

Introduction – Why two-bladed turbines?

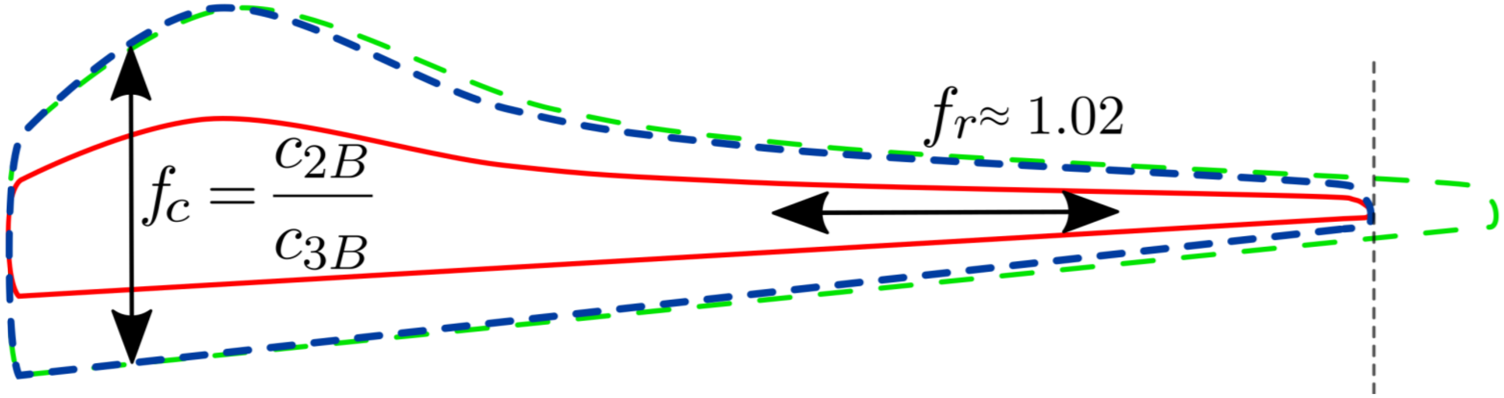
Offshore:

Pro	Contra
• Cheaper rotor and drivetrain	• More noise • More unpleasant looks • **Lower power coefficient (Cp)** ➢ **Extend rotor size by 2%[1]**
• Faster and easier erection	
• Less components to maintain	• **More harmful dynamics**
• Better access by helicopter	➢ Today better controllable (active or passive) ➢ Size effect
• Lower turbine head mass	



[1] F. Anstock et. al., *A new approach for comparability of two- and three-bladed 20 MW offshore wind turbines*, Journal of Physics: Conference Series, 2019

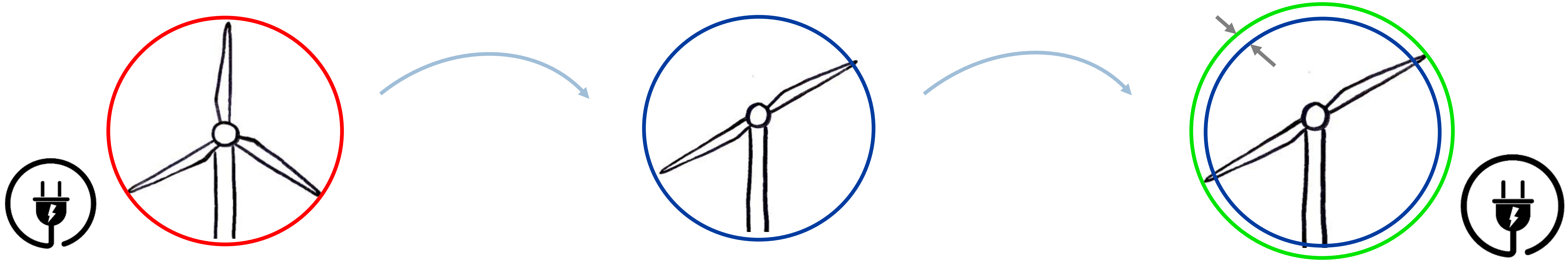
Three- and two-bladed reference turbines – design process



3-Bladed INNWIND 20 MW as reference turbine

Redesign the blades with similar aerodynamics[1] and ~50% higher strength and buckling resistance[2]

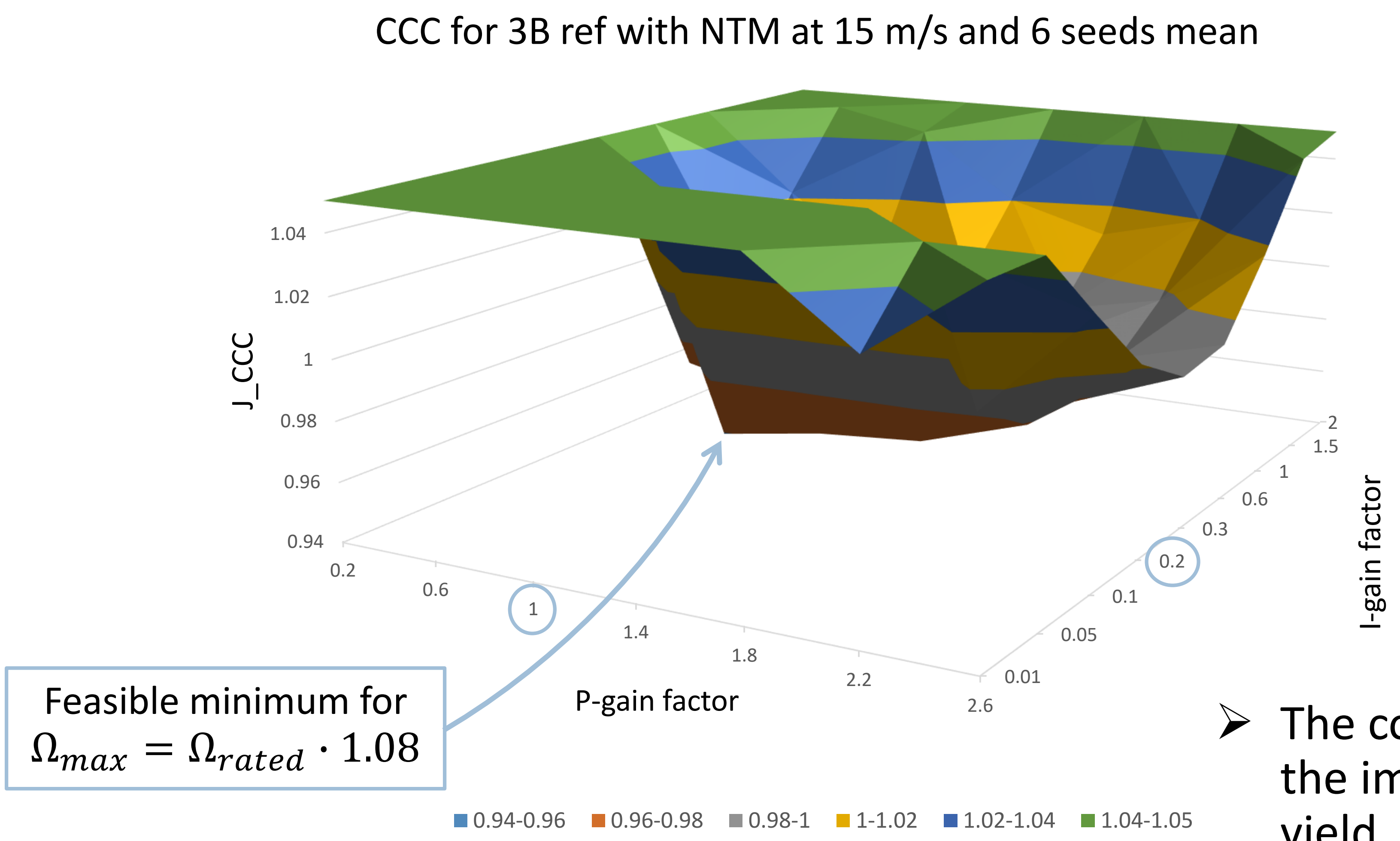
2-Bladed reference turbine with equal power curve



[1] F. Anstock et. al., *A new approach for comparability of two- and three-bladed 20 MW offshore wind turbines*, J. Phys.: Conf. Ser., 2019

[2] M. Schütt et. al., *Progressive structural scaling of a 20 MW two-bladed offshore wind turbine rotor blade examined by finite element analyses*, J. Phys.: Conf. Ser., 2020

Three- and two-bladed references – Objective PI-gain tuning[1]



- The control cost criterion (CCC) estimates the impact on costs of pitch activity, energy yield, tower, hub and blade loads (for DLC 1.2) to achieve a good compromise between conflicting objectives

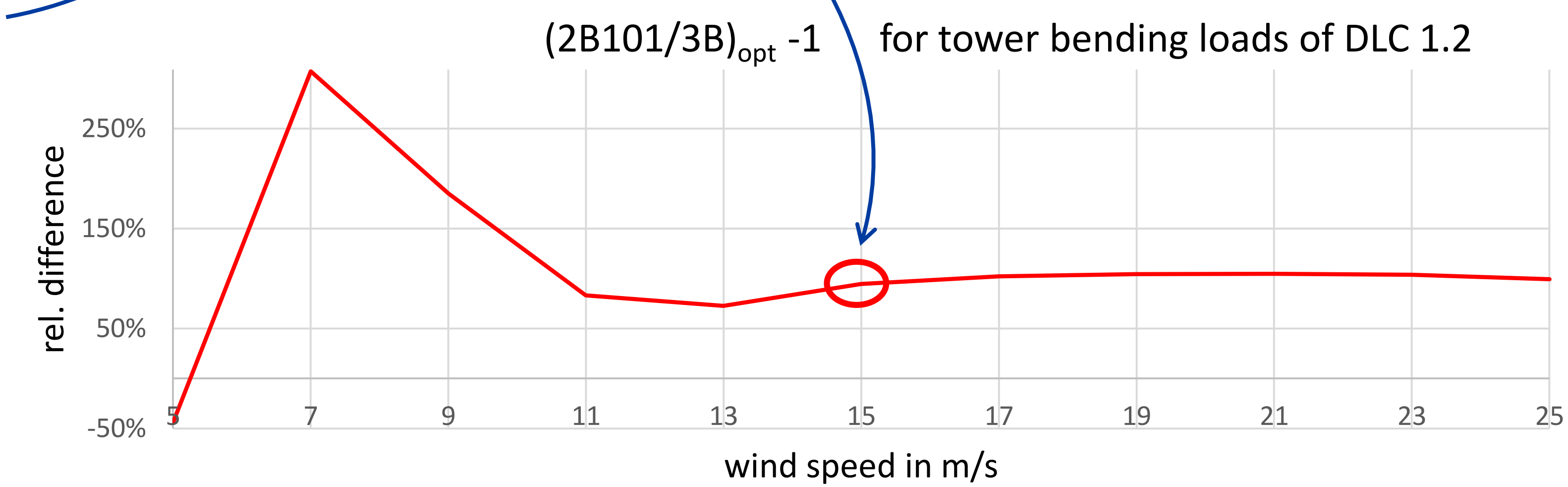
[1] F. Anstock et. al., *A control cost criterion for controller tuning of two- and three-bladed 20MW offshore wind turbines*, J. Phys.: Conf. Ser., 2020

Three- and two-bladed references – first load comparison NTM 15 m/s

- The described procedure leads to following results for 15 m/s NTM and a rated tip speed of 90 and 100 m/s for the 2-bladed turbines[1]:

	$(2B90/3B)_{opt}$ -1	$(2B100/3B)_{opt}$ -1
$L'_{M_y,blade}$	$+52.2\,\%$	$+41.2\,\%$
$L_{M_{y'},tower}$	$+212.8\,\%$	$+89.4\,\%$
$\int P$	$+0.0\,\%$	$+0.0\,\%$

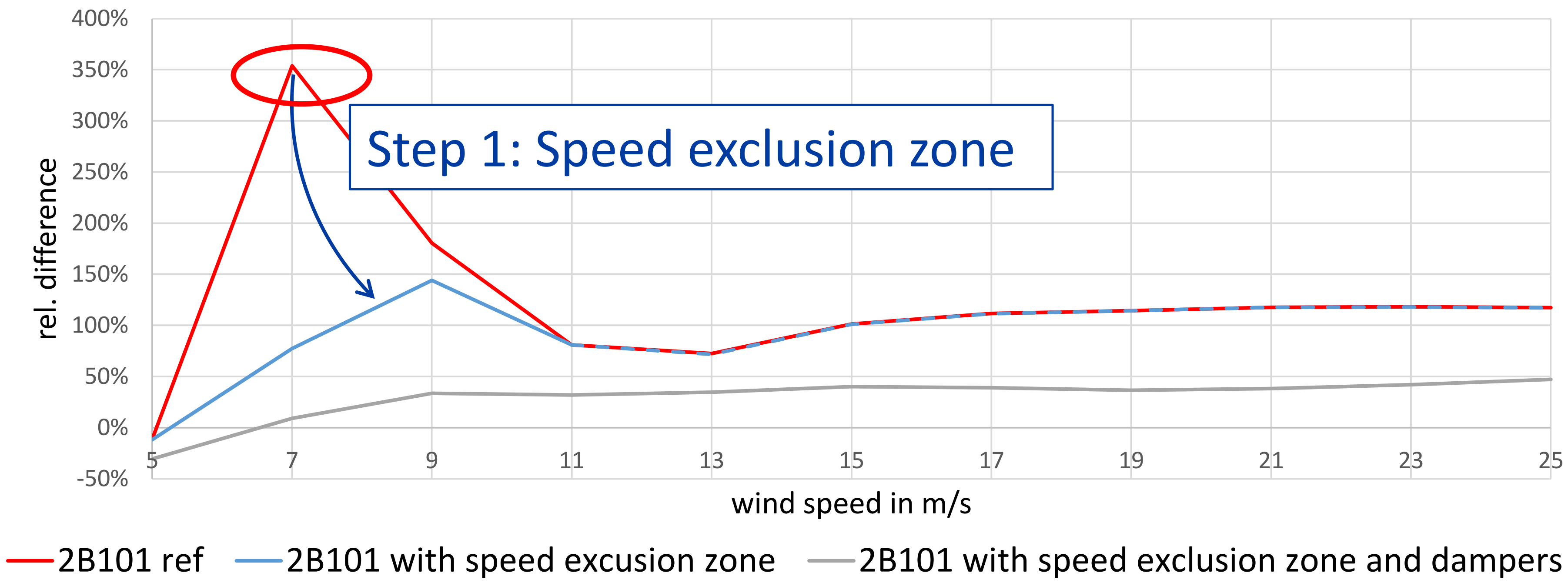
- Lower loads for higher tip speed



[1] F. Anstock et. al., *A control cost criterion for controller tuning of two- and three-bladed 20MW offshore wind turbines*, J. Phys.: Conf. Ser., 2020

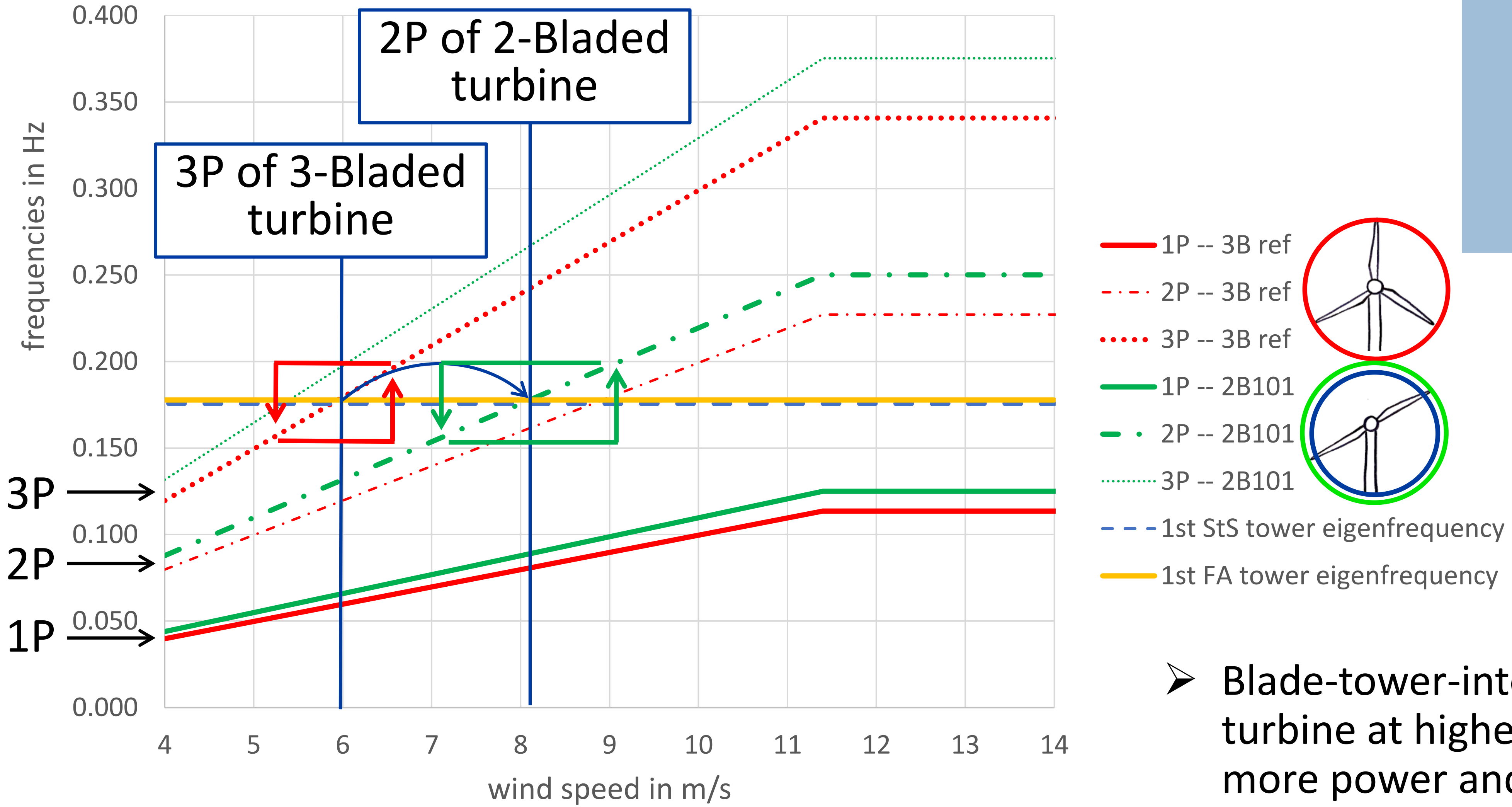
Speed exclusion zone – challenging dynamics

relative differences of DLC 1.2 tower loads compared to 3B with speed exclusion zone and dampers



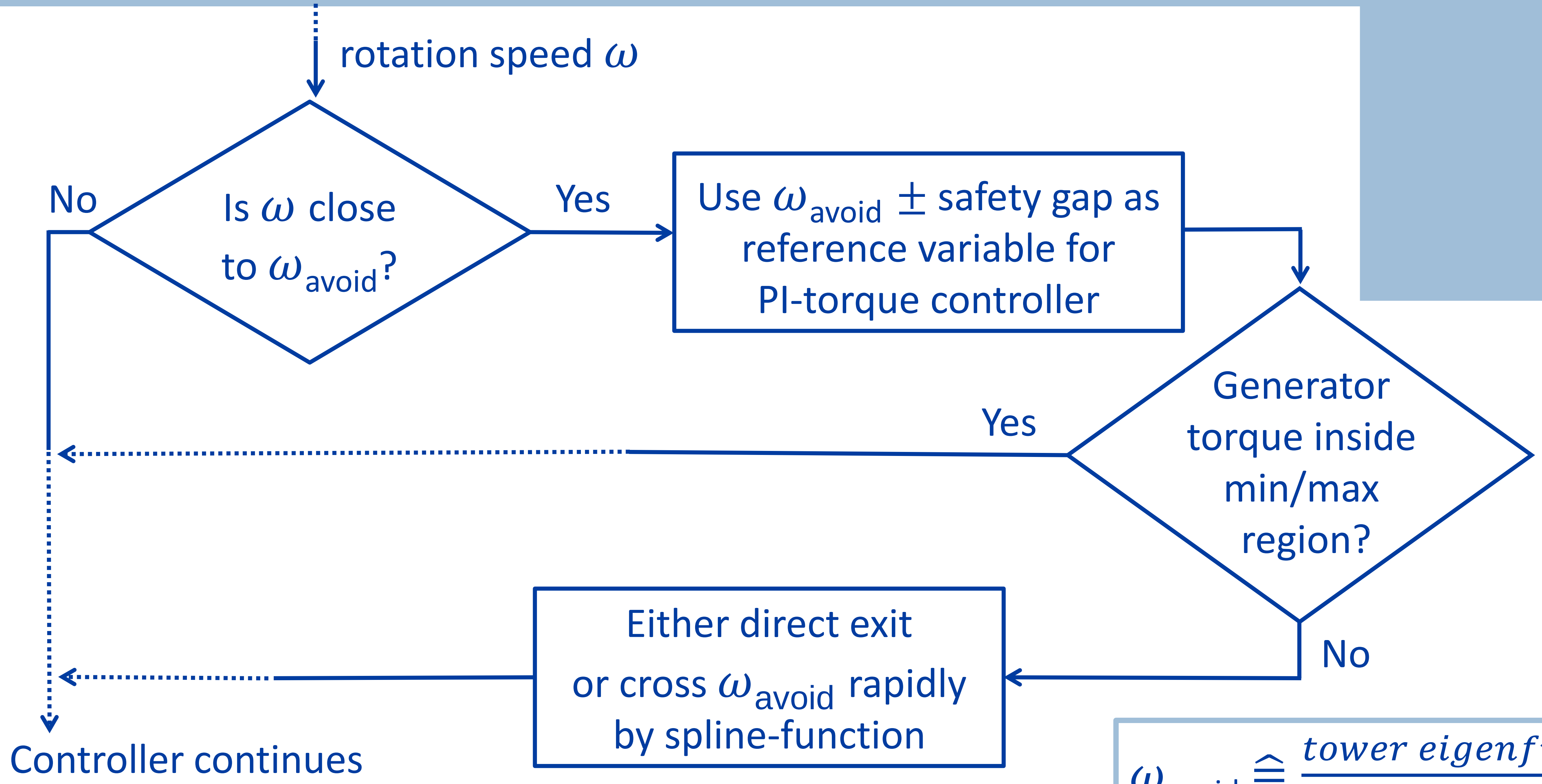
Speed exclusion zone – Campbell diagram

Tower frequency excitation by passing blades shifts:



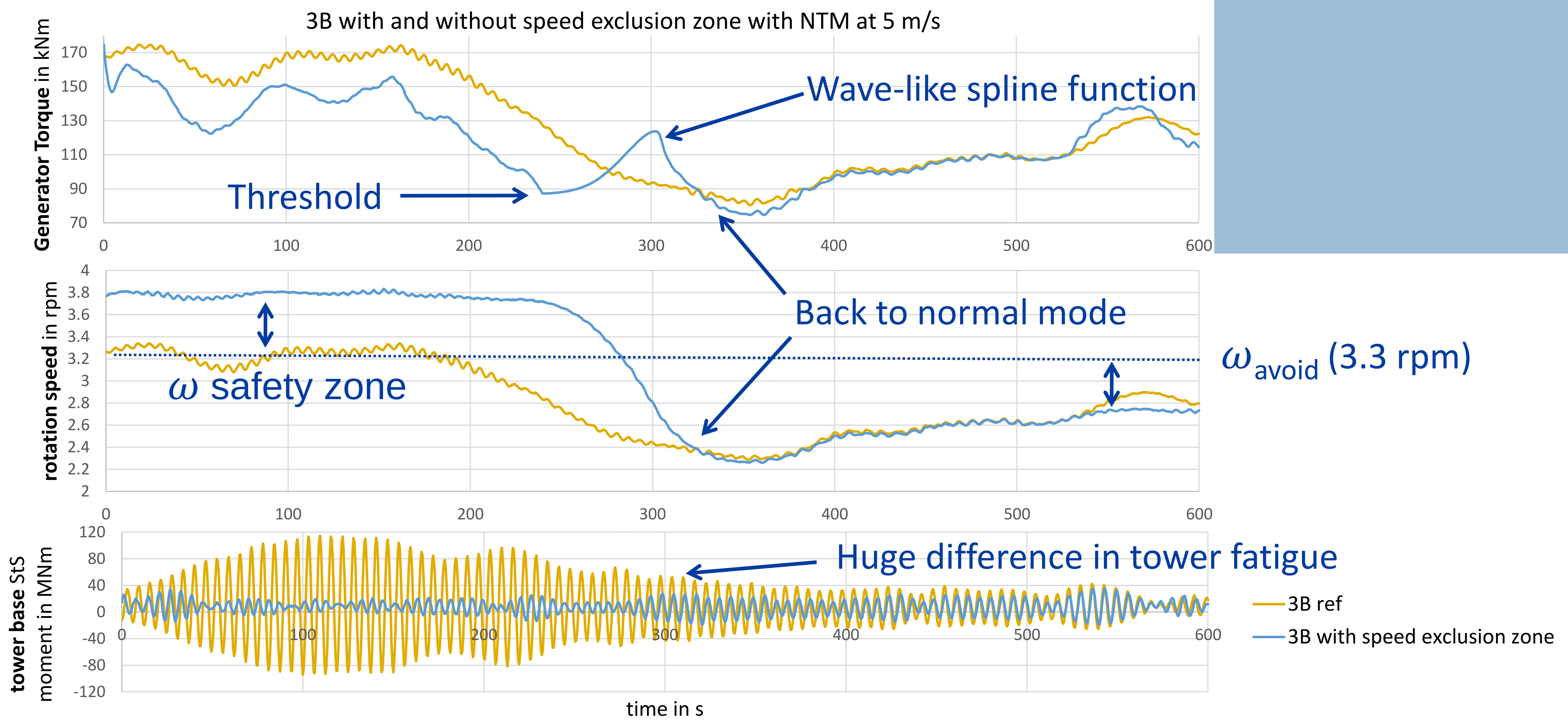
- Blade-tower-interference for 2-Bladed turbine at higher wind speeds with more power and higher occurrence

Speed exclusion zone – how does it work? Basic procedure

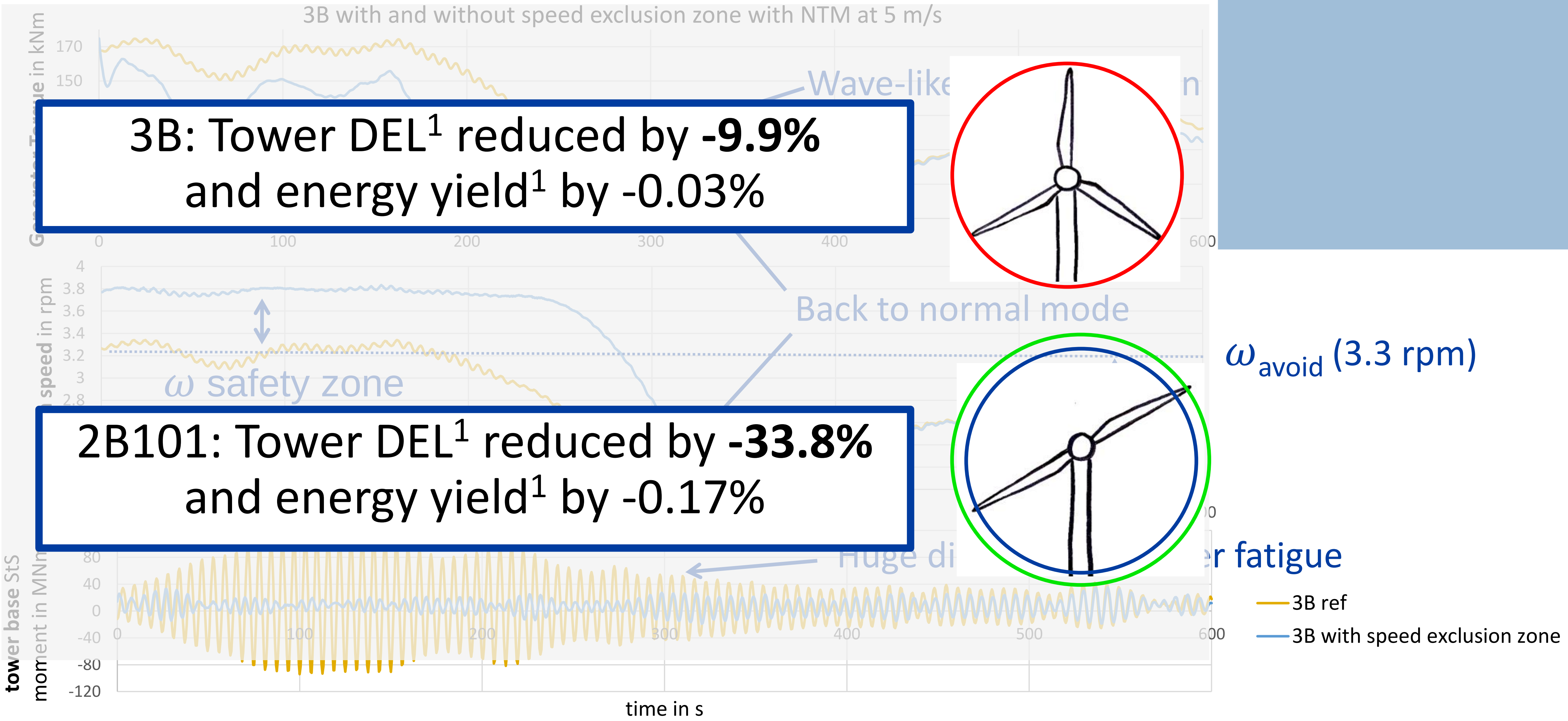


$$\omega_{avoid} \mathrel{\hat{=}} \frac{tower\ eigenfrequency}{number\ of\ blades}\,60$$

Speed exclusion zone – how does it work? Example



Speed exclusion zone – how does it work? Example



3B: Tower DEL[1] reduced by -9.9% and energy yield[1] by -0.03%

2B101: Tower DEL[1] reduced by -33.8% and energy yield[1] by -0.17%

[1] DLC 1.2 with 0°, +-8° yaw and Rayleigh distribution with 11.4 m/s mean wind speed

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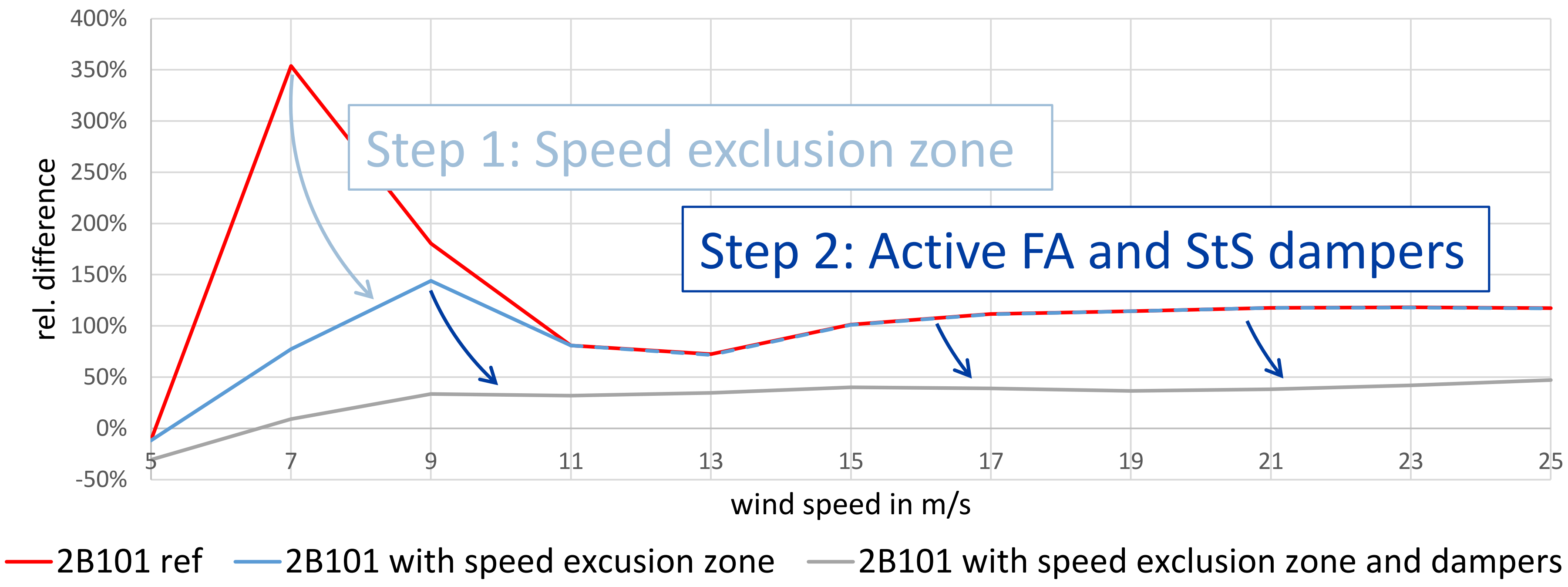
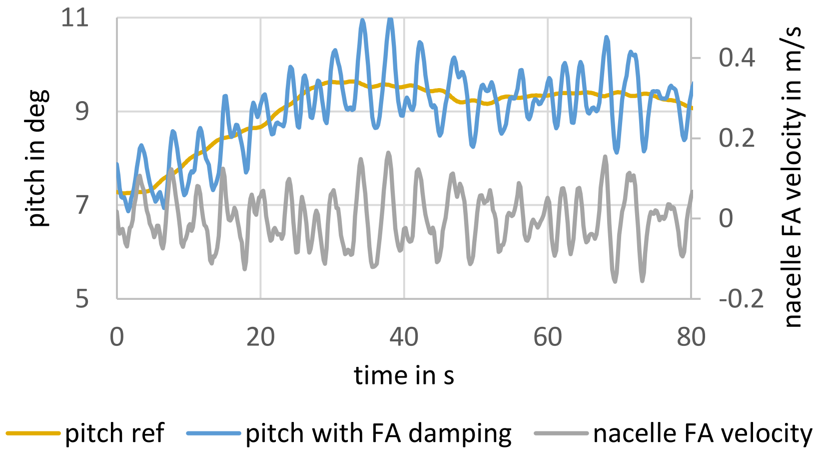
Active tower dampers – challenging dynamics

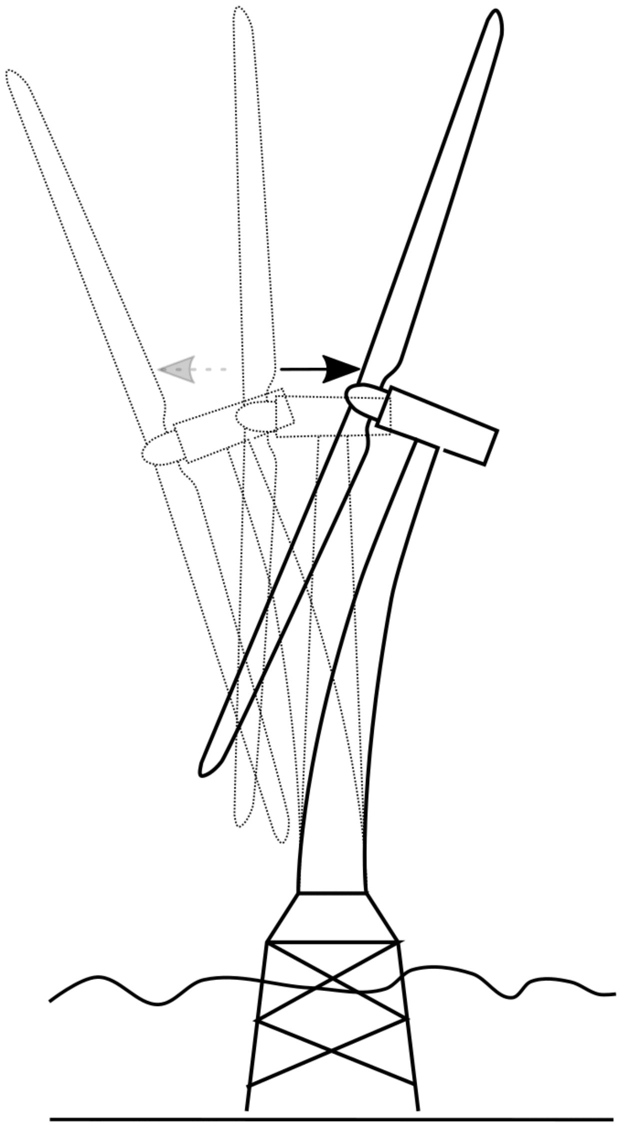
relative differences of DLC 1.2 tower loads compared to 3B with speed exclusion zone and dampers



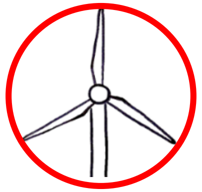
Basic active **fore-aft** (FA) tower damper

- Measure **fore-aft acceleration** and integrate to FA **velocity**
- Apply tower FA velocity signal with a gain **directly on demanded pitch signal**

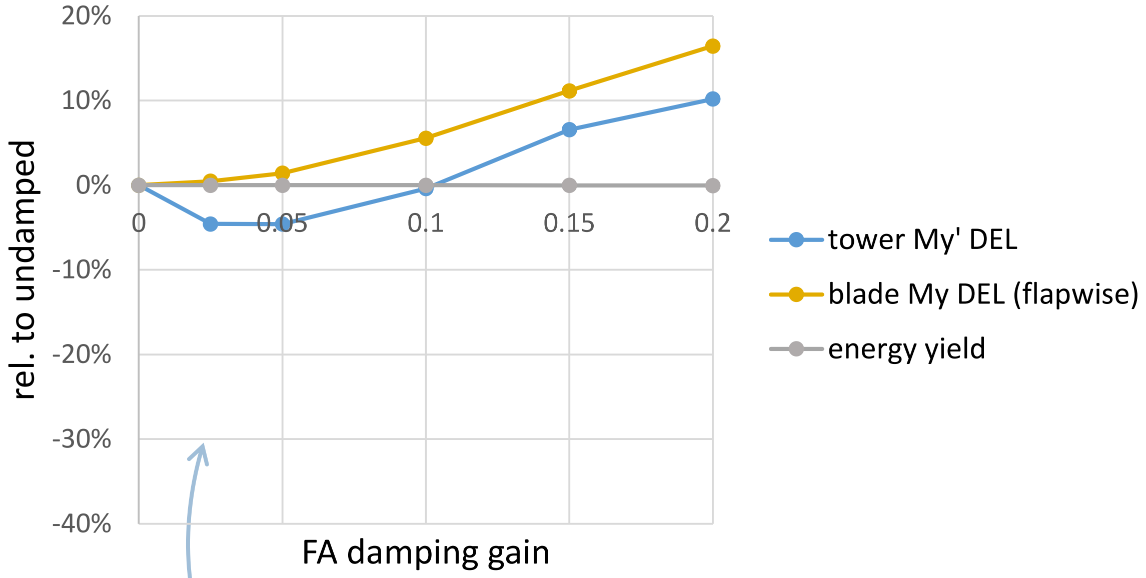




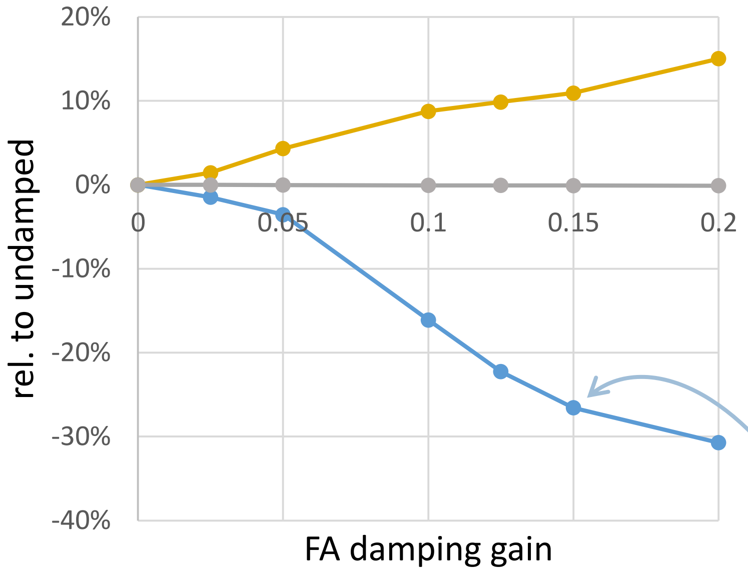
Basic active **fore-aft** (FA) tower damper



3B FA damping for 11-25 m/s



2B101 FA damping for 11-25 m/s



Reasonable gain for **3B** is 0.03:

Tower DEL reduced by **-4.57%**,
energy yield by -0.0001% and
Blade My (flapwise) DEL increased by 0.46%

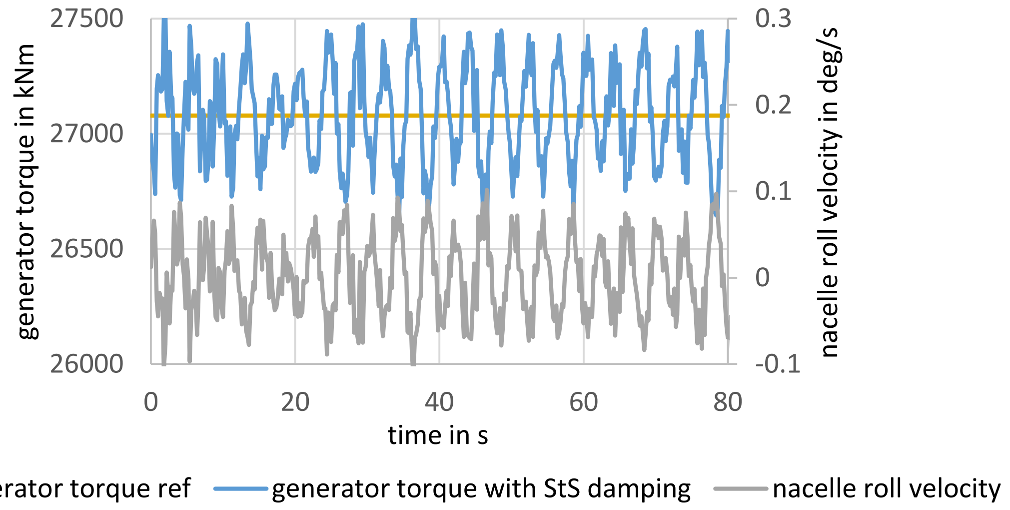
- Almost no energy loss present
- Less benefits for the three-bladed turbine's tower, but blade loads almost unchanged

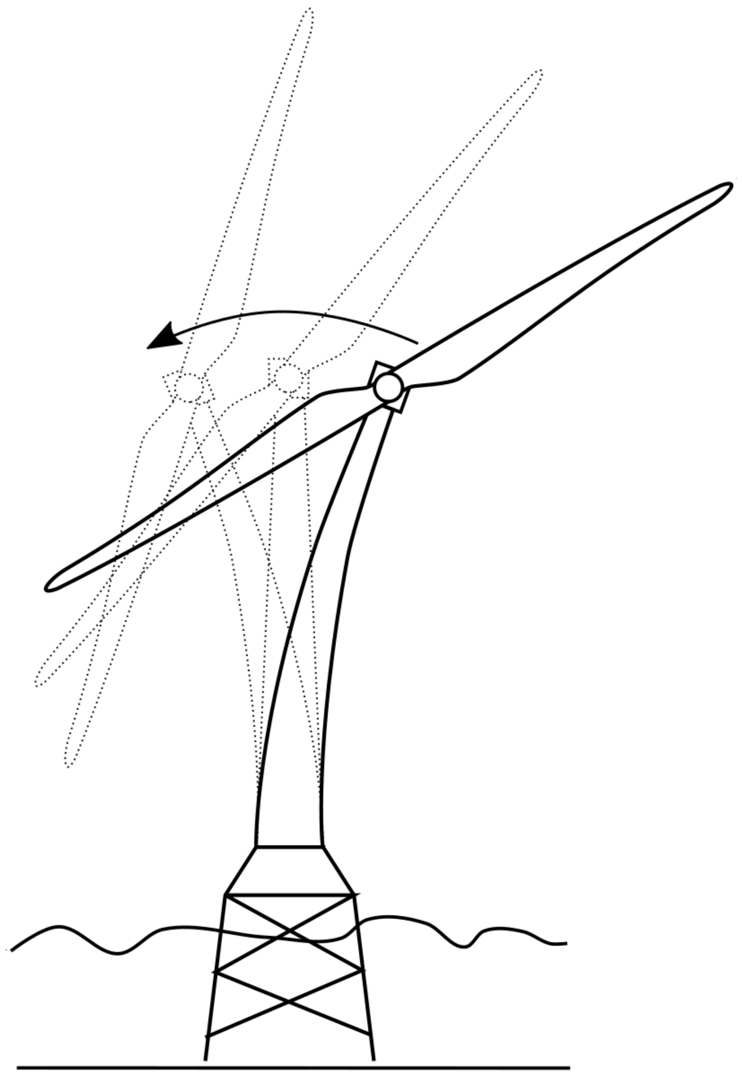
Reasonable gain for 2B101 is 0.125:

Tower DEL reduced by -26.57%,
energy yield by -0.08% and
Blade My (flapwise) DEL increased by 10.9%

Basic active **side-to-side** (StS) tower damper

- Measure nacelle **roll acceleration** and integrate to the **roll velocity**
- Apply nacelle roll velocity with a gain **directly on demanded generator torque**





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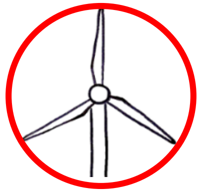
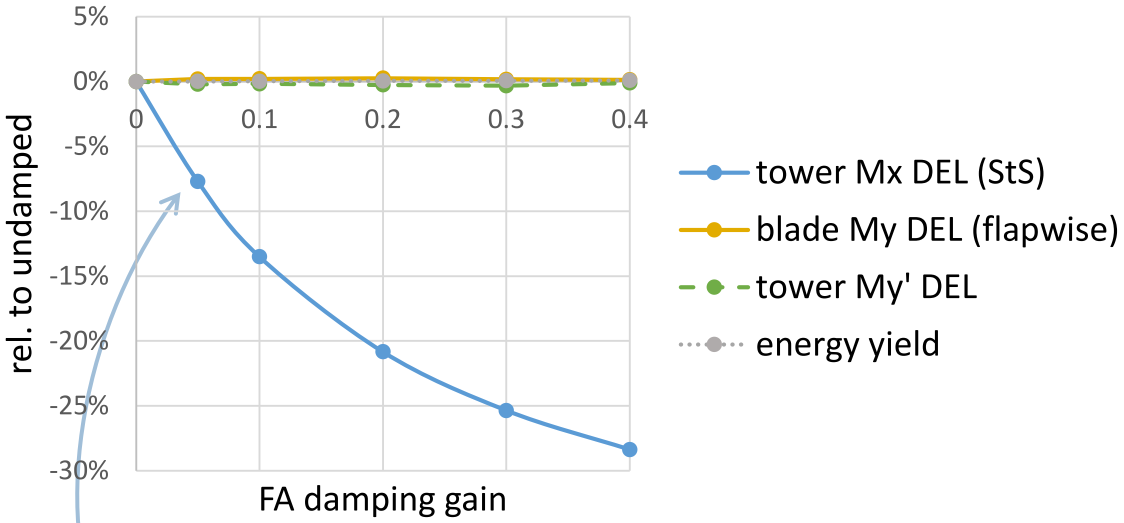
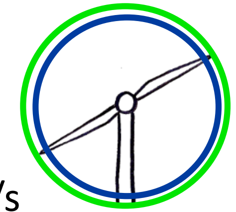
Basic active **side-to-side** (StS) tower damper

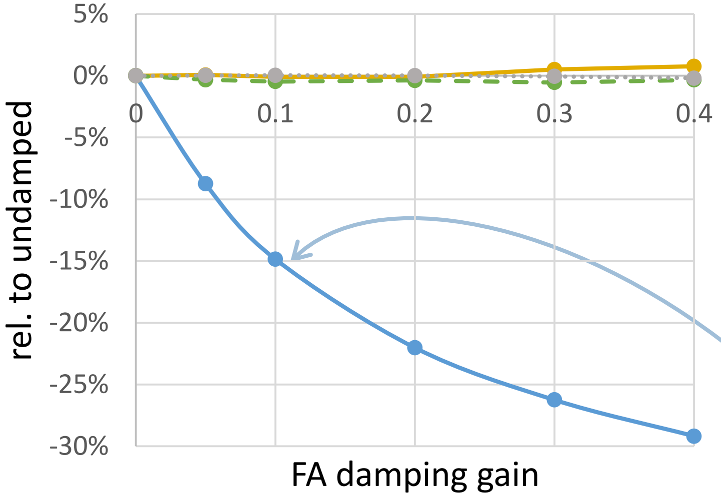


3B StS damping for 11-25 m/s





2B101 StS damping for 11-25 m/s



(Reasonable) gain for **3B** is 0.05:

Tower Mx DEL reduced by **-7.7%,** and combined tower DEL by **-0.21%;** energy yield increases by +0.01%

- The StS damping by generator works well
- Has only a small effect on the combined tower DEL My‘ for 2B101 and 3B in full load operation
- During partial load the influence is bigger.

(Reasonable) gain for **2B101** is 0.1:

Tower Mx DEL reduced by **-14.9%** and combined tower DEL by **-0.47%;** energy yield increases by +0.02%

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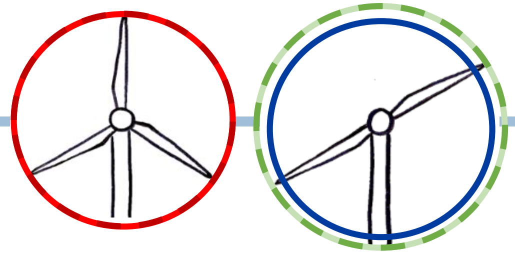
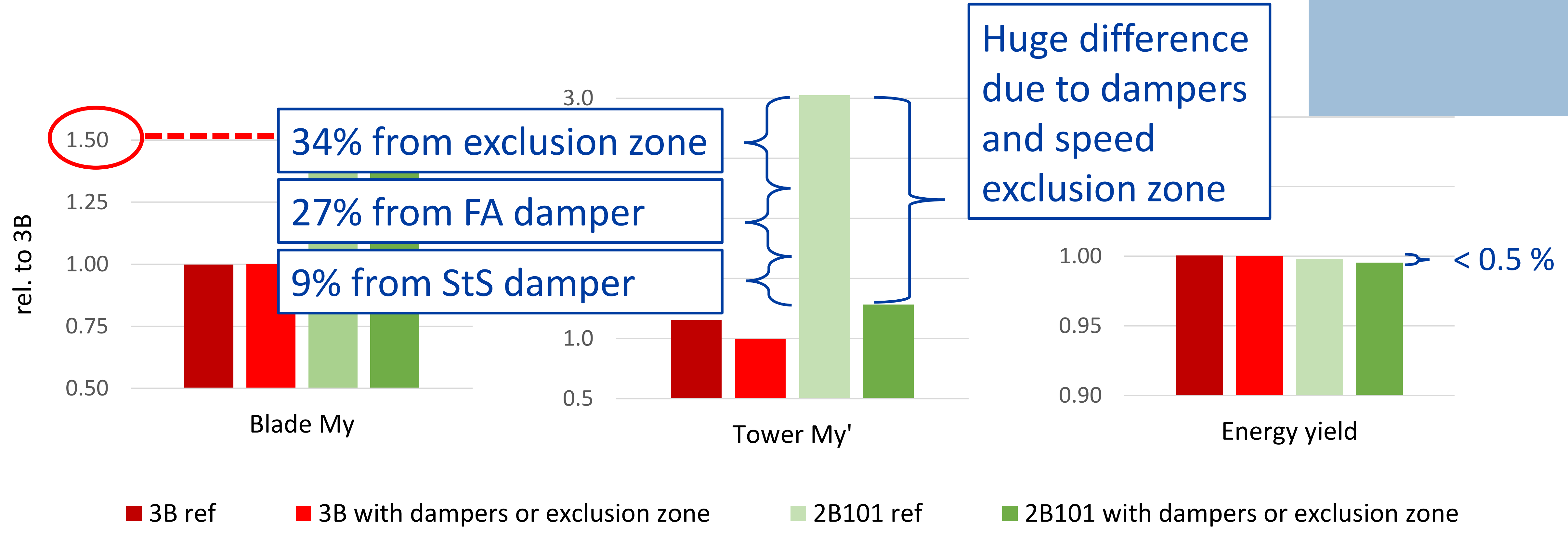
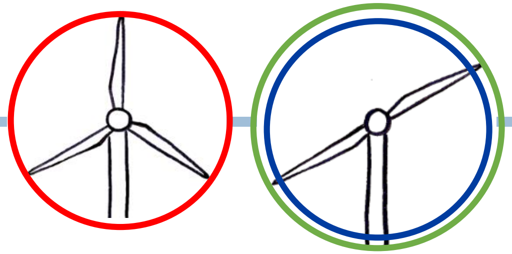
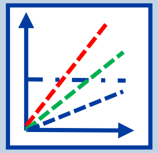
Final load comparison – fatigue by DLC 1.2



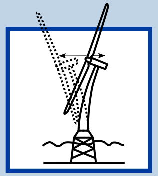


Summary and Conclusions





A **speed exclusion zone** can be a good countermeasure against 2P or 3P excitation of the tower eigenfrequency, reducing tower fatigue (loads) by **10%** for three-bladed and **33%** for two-bladed.



Simple collective pitch driven **tower fore-aft damping and side-to-side damping** by the generator torque reduce tower fatigue efficiently by **another 36%** for the two-blade turbine.

The proposed control features reduce the two-bladed turbine‘s tower loads already **from 170% to 28%** above an equivalent three-bladed turbine. With teetering, MPC, IPC or free-yaw, this difference might shrink even more, potentially rectifying the largest drawback of two-bladed turbines – the more harmful dynamics.

Funded by Federal Ministry for Economic Affairs and Energy & SIEMENS Gamesa RENEWABLE ENERGY

Source: Levin Schilling

Thank you for your attention!

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